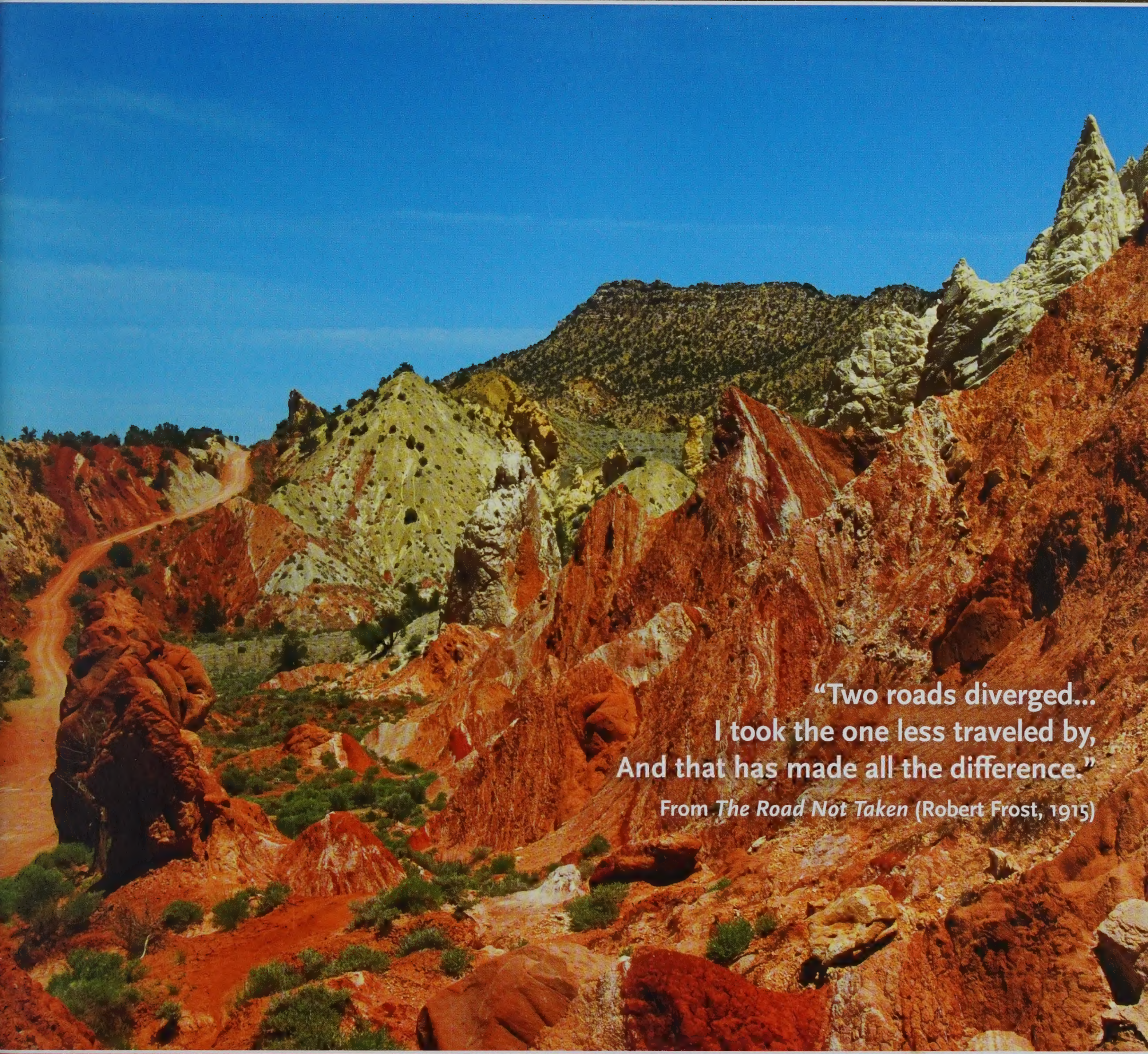
H GEOLOGICAL SURVEY

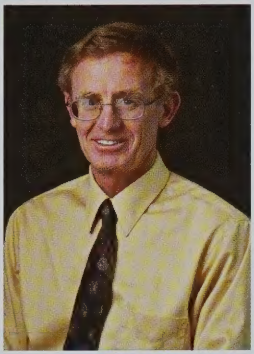
# SURVEY NOTES

Volume 42, Number 1 January 2010



"Two roads diverged...
I took the one less traveled by,
And that has made all the difference."
From *The Road Not Taken* (Robert Frost, 1915)

# THE DIRECTOR'S PERSPECTIVE

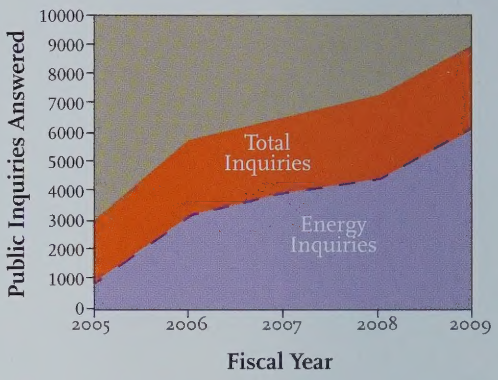


by Richard G. Allis

This issue of *Survey Notes* highlights the breadth of energy expertise within the Utah Geological Survey (UGS). In addition to conducting research in the traditional fossil energy areas of oil, gas, and coal, and non-traditional resources such as oil shale and tar sands, the UGS also manages the Utah State Energy Program (USEP) which is responsible for administering local federal initiatives to stimulate energy efficiency and renewable energy projects in Utah. The largely non-regulatory role of the UGS enables us to focus on providing the best possible objective information about resource potential within the state. We maintain the statistics on historical energy use trends in the state (visit geology.utah.gov/emp/energydata/index.htm), provide the energy chapter for the Annual Economic Report to the Governor, and provide regular input on resource production trends to the Revenue Assumptions Committee of the Governor's Office of Planning and Budget. The major challenge for the USEP at the moment is ramping up the programs to disperse \$50 million in federal "stimulus" funds within the state over the next two years.

The economic boom-to-bust cycle over the past two years continues to ripple through Utah's energy sector and can be seen in the energy statistics. Natural gas prices remain depressed compared to what is needed to sustain production, the number of active drilling rigs is now only 35 percent of what it was 16 months ago, and total energy consumption in the state for 2009 will likely be down by at least 5 percent compared to 2008. However, total production of oil and gas in Utah for 2009 is projected to continue the upward trend of previous years (see page 4), with marketed gas production setting a new record of about 455 billion cubic feet (bfc) compared to 432 bcf in 2008. Half of this gas is exported for use in other states. Not all new production has been in fossil fuels. Two renewable energy power plants were commissioned this year—the 10 megawatt Hatch geothermal power plant near Minersville, and First Wind's 240 megawatt wind farm near Milford.

The national challenges of sustaining a secure and affordable energy supply for the future will ensure that energy issues remain center stage, especially with the concerns that carbon dioxide emissions need to be managed. Two relevant areas where the UGS is active are the feasibility of geological sequestration of $CO_2$, and improving energy efficiency and the use of renewable energies. Both areas have the potential to significantly reduce the state's $CO_2$ emissions.



One dramatic trend that the UGS has seen over the past five years is the number of inquiries we receive about energy-related issues. There are a number of reasons for the progressive rise in inquiries, but overall it demonstrates the growing importance of energy issues to all sectors of Utah's economy. It also shows the important role that the UGS is now playing in supplying critically needed energy information.

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**Design:** *Stevie Emerson*

**Cover:** *Vertical beds of the Middle Jurassic Carmel Formation are displayed along The Cockscomb, part of the East Kaibab monocline in Grand Staircase–Escalante National Monument.*
*Photo by Michael Vanden Berg.*

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# UTAH POTASH

## Resources, Production, and Exploration

by Bryce T. Tripp

### INTRODUCTION

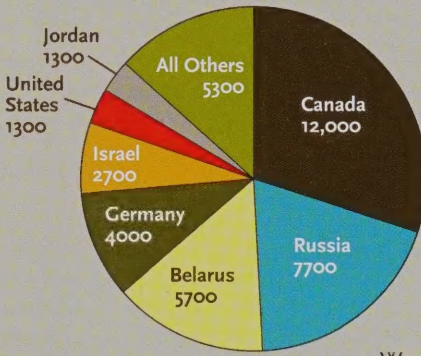
The word potash refers to a group of naturally occurring potassium-bearing minerals, the most common of which is sylvite (potassium chloride). Potash is used to manufacture a variety of products including soap, glass, synthetic rubber, and explosives. Potash is also an essential plant nutrient, and 93% of the potash mined in the world is used as plant fertilizer. The word originates from the historical practice of burning wood to obtain potassium carbonate-bearing ash which was then leached and precipitated in iron pots—"pot ash." This nutrient is contained in all balanced fertilizer mixes. Bags of fertilizer are labeled with an N-P-K code like 30-10-10; the first number indicates the nitrogen content (N), the second number indicates the phosphorous content (P), and the third number indicates the potassium content (K).

*Horticultural test plot in Brazil showing growth of soybeans with no added potash fertilizer (yellow, stunted plants in foreground) versus potash-fertilized plants (vigorous green plants in background). Photo credit: International Potash Institute.*

Potassium is found in a variety of salts, is a common element in many rock-forming minerals, and is the 7th-most common constituent of the Earth's continental crust (about 2%). It is most concentrated and in a water-soluble form in (1) surface and subsurface brines of closed-basin lakes and (2) restricted marine basin (evaporite) deposits. Evaporite deposits worldwide are the most economically important sources of potash. Evaporite minerals precipitated out of concentrated sea water in geologic basins that were partially restricted from the open ocean. Minerals dissolved in sea water precipitate sequentially from solution (during evaporation) based on their solubilities so carbonate minerals precipitate first, then sulfates, and finally chlorides. Sylvite is one of the last salts precipitated; almost all of the water in brine has evaporated before sylvite starts to precipitate.

In 2008 the U.S. Geological Survey (USGS) reported that world production of potash was about 40 million tons ($K_2O$ equivalent); seven countries produced most of that amount. Canada, Russia, and Belarus are the three largest potash producers. The USGS estimates a world resource of 276 billion tons ($K_2O$), a U.S. resource of 7.7 billion tons ($K_2O$), and a Utah resource of 2.2 billion tons ($K_2O$).

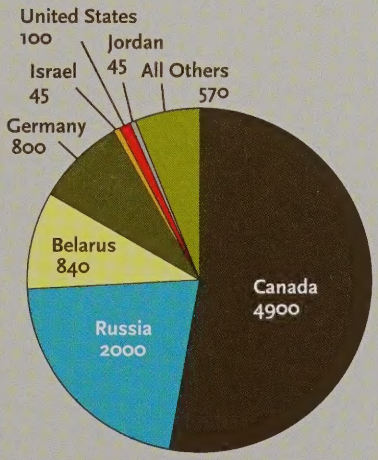
World Potash Production, 2008
(thousands of short tons $K_2O$)



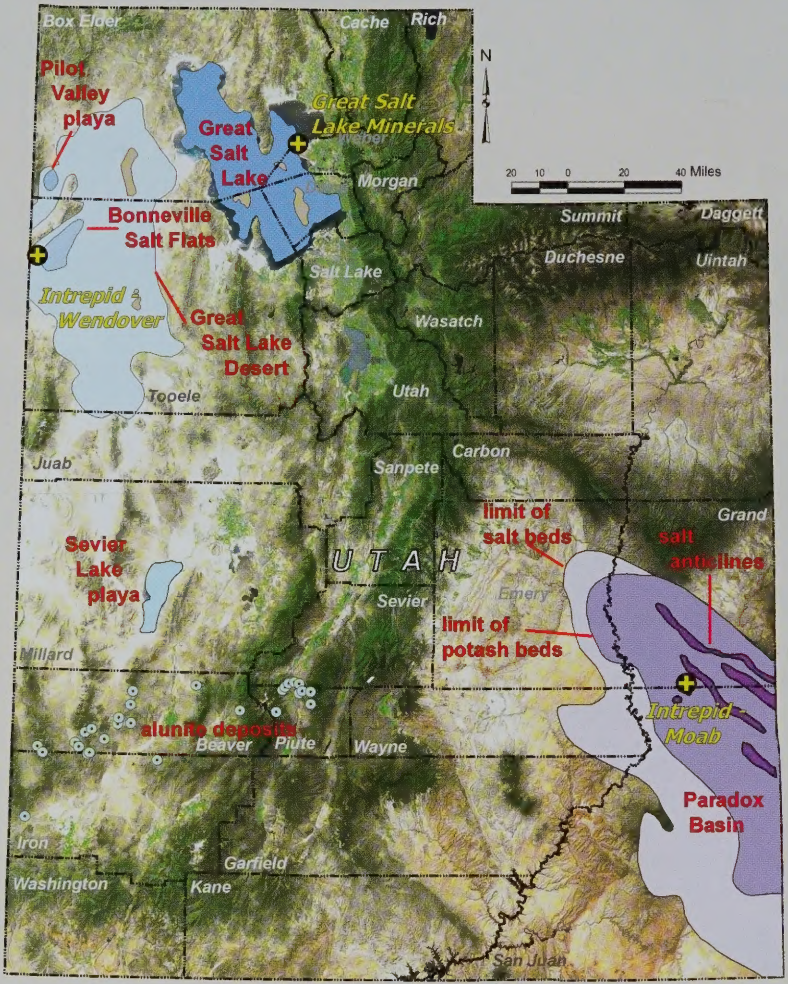
*U.S. Geological Survey data.*

Potash prices have historically been very stable; between 1994 and 2003 the price remained in the range of $146 to $179 per ton. The potash price started rising in 2005 and during 2008 spiked to more than $900 per ton, but by mid-2009 had declined to about $500 per ton. Increased potash prices were caused by an increased standard of living in developing countries (with increased use of chemical fertilizer) and also increased use of fertilizer for ethanol production from corn.

World Potash Reserves, 2008
(millions of short tons $K_2O$)



*U.S. Geological Survey data.*



*Utah's potash resources, including resource areas (colored polygons) and individual alunite deposits (colored circles). Potash production locales shown by yellow crosses.*

## POTASH DEPOSITS OF UTAH

Utah contains substantial potash resources, and potash has been an important mineral product in the state since 1917. Significant quantities of potash are contained in (1) surface brine of Great Salt Lake, (2) subsurface brine of the Great Salt Lake desert, (3) subsurface brine of the Sevier Lake playa, (4) potash beds and associated subsurface brines of the Paradox Basin, and (5) alunite (potassium aluminum sulfate) vein and replacement deposits distributed across southwestern Utah.

Two companies currently produce potash in Utah. Great Salt Lake Minerals Corporation produces more than 400,000 tons of potash (potassium sulfate) each year by solar evaporation of surface brine of the north part of Great Salt Lake at their plant west of Ogden. They are currently trying to obtain permits for 80,000 acres of additional solar evaporation ponds to increase their production. Intrepid Potash, Inc., processes shallow subsurface brines through its solar evaporation ponds and plant at Wendover. Intrepid also solution mines Paradox Basin bedded potash and processes it through their Moab (Cane Creek) solar ponds and mill.

The high potash prices of the past few years have encouraged a flurry of potash exploration and development worldwide, including in Utah. The Paradox Basin has received more interest than other Utah potash resources because it is the largest resource with the most opportunities for new developments.

## PARADOX BASIN POTASH

### Structure and Stratigraphy

The Paradox Basin bedded potash is contained in the northwest-trending Paradox Basin of Pennsylvanian to Permian age (about 300 million years ago). The Paradox Basin is bounded on the northeast by the Uncompahgre uplift, an uplifted fault block of the Ancestral Rockies. As the Uncompahgre began to rise in Pennsylvanian time, the adjacent Paradox Basin began to subside with the deepest part of the basin adjacent to the Uncompahgre. Salt was deposited in this basin during Pennsylvanian time. A combination of variable salt thickness and salt flowage after burial warped the salt into a series of northwest-trending salt anticlines where the salt is thickened (and often folded and faulted), separated by synclines where the salt is dramatically thinned.

As the Paradox Basin began subsiding, a few hundred feet of predominantly carbonate sediments were deposited as the Pennsylvanian Pinkerton Trail Formation of the Hermosa Group. The basin then became partially restricted from the open sea and as much as 5000 feet of predominantly evaporite sediments (gypsum, halite, potash, and magnesium salts) were deposited as the Paradox Formation of the Hermosa Group. Fluctuations in sea level, and probably in basin subsidence rates, resulted in deposition of 29 rhythmically bedded evaporite cycles; in 18 of the cycles, evaporation proceeded to the point of potash deposition. The salt cycles in the Paradox Formation are often laterally continuous and can be traced, through interpretation of well logs, in the subsurface for tens of miles. The depositional center of the basin shifted over time and the basin floor had varied topography, so not all 29 salt cycles are stacked vertically at any one point in the basin. In the 1960s, Robert Hite (with the USGS) devised a stratigraphic framework for the salt cycles, numbering them from 1 (shallowest) to 29 (deepest) and correlated them across the Paradox Basin. Intrepid Potash, Inc., solution mines the potash of salt cycles 5 and 9 at its Moab mine.

### Potash Resource

The salt-bearing zone in the Paradox Basin is about 4000 feet thick and is composed of 10 percent potash beds, 25 percent shale beds (with anhydrite and dolomite), and 65 percent halite beds. Usually eight to 10 potash zones underlie the potash resource areas of the basin and have an aggregate thickness ranging from 220 to 460 feet. In 1965 the U.S. Bureau of Mines estimated the Paradox Basin known potash reserves to be 254 million tons ($K_2O$ equivalent) with an inferred reserve of 164 million tons ($K_2O$ equivalent). This estimate was based on underground mining of potash beds greater than 4 feet thick, containing more than 14 percent $K_2O$ content, and at depths less than 4000 feet. Due to potash deposit complexity, safety issues with underground mining in the Paradox Basin, and improvements in horizontal drilling technology, any future development will likely be by solution mining. Solution mining through drill holes may make potash from beds as deep as 9000 feet recoverable, greatly expanding the potash resource. Some of the oil and gas wells drilled between 1965 and the present penetrated the potash zone; this additional information would probably increase the U.S. Bureau of Mines potash reserve estimates listed above.

*Great Salt Lake Mineral's potash evaporation ponds and plant looking north from Little Mountain.*

*Intrepid Potash's Wendover plant looking north across the solar evaporation ponds to the plant with the Silver Island Mountains in the background and snow-covered Pilot Range in the distance.*

*Intrepid Potash's solar evaporation ponds near Moab. The blue color is caused by dye added to the brine to increase evaporation. The dry potash is harvested and hauled for processing at the plant located in the upper-right part of the image. Photo credit: Intrepid Potash, Inc.*

## Future Development

The Utah School and Institutional Trust Lands Administration and the U.S. Bureau of Land Management (BLM) have met with many companies about exploration and leasing of land in the Paradox Basin. However, there are a few hurdles to new development: (1) the BLM needs to re-examine their Known Potash Leasing Area boundaries before granting new leases, (2) the recent world credit crisis has made funding for new developments difficult to obtain, and (3) the price for potash has declined from its peak at the end of 2008. Even with these hurdles, development of new solution mines in the Paradox Basin seems possible if potash prices remain at their relatively high level or increase. ■

## FURTHER READING

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## ABOUT THE AUTHOR

Bryce Tripp has worked with the Utah Geological Survey since October 1979 as an industrial mineral geologist, project manager, section chief, and program manager. He graduated from the University of Utah, Department of Geology, with a B.S. degree in 1977. Bryce has studied tar sand, zeolite, high-calcium limestone, dimension stone, gypsum, sand and gravel, gilsonite, and potash resources of Utah. He has also worked on long-term projects providing industrial mineral information to state and federal land management agencies. He is a member of the American Association of Petroleum Geologists and Society for Mining, Metallurgy, and Exploration Inc., and is a member and past president of the Utah Geological Association. Bryce retired from state employment in December 2009.

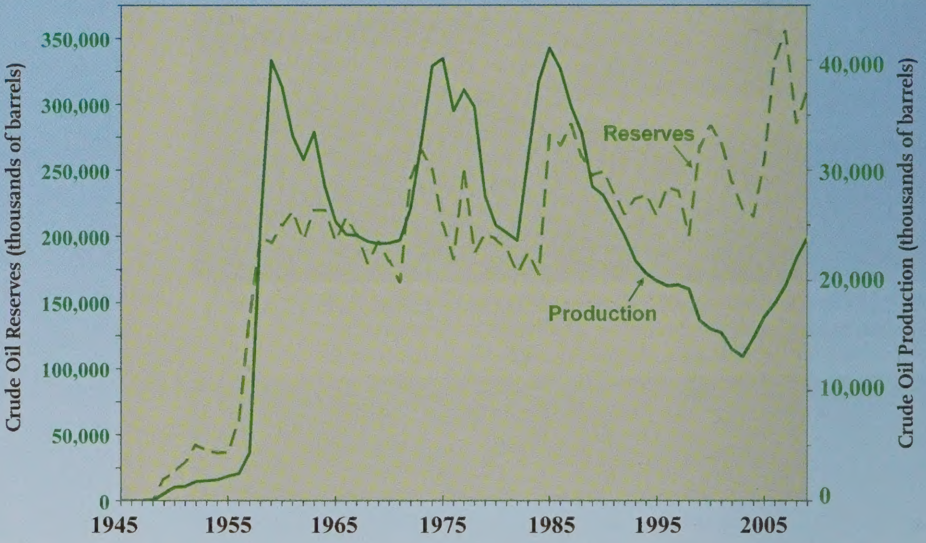
# MAJOR OIL PLAYS

## IN UTAH AND VICINITY

*by Thomas C. Chidsey, Jr.*

### Introduction

One of the benefits of Utah's diverse geology is a wealth of petroleum resources. Three oil-producing provinces exist in Utah and adjacent parts of Wyoming, Colorado, and Arizona—the thrust belt, Paradox Basin, and Uinta Basin. Utah produces oil from eight major "plays" within these provinces, where a play is defined by the U.S. Geological Survey as a set of known or postulated oil accumulations sharing similar geologic, geographic, and temporal properties such as hydrocarbon-generating source rocks, oil migration pathways, trapping mechanisms, and hydrocarbon types. The Utah Geological Survey (UGS) has recently completed a study, funded in part by the U.S. Department of Energy, that describes concisely and in new detail each of these major oil plays.

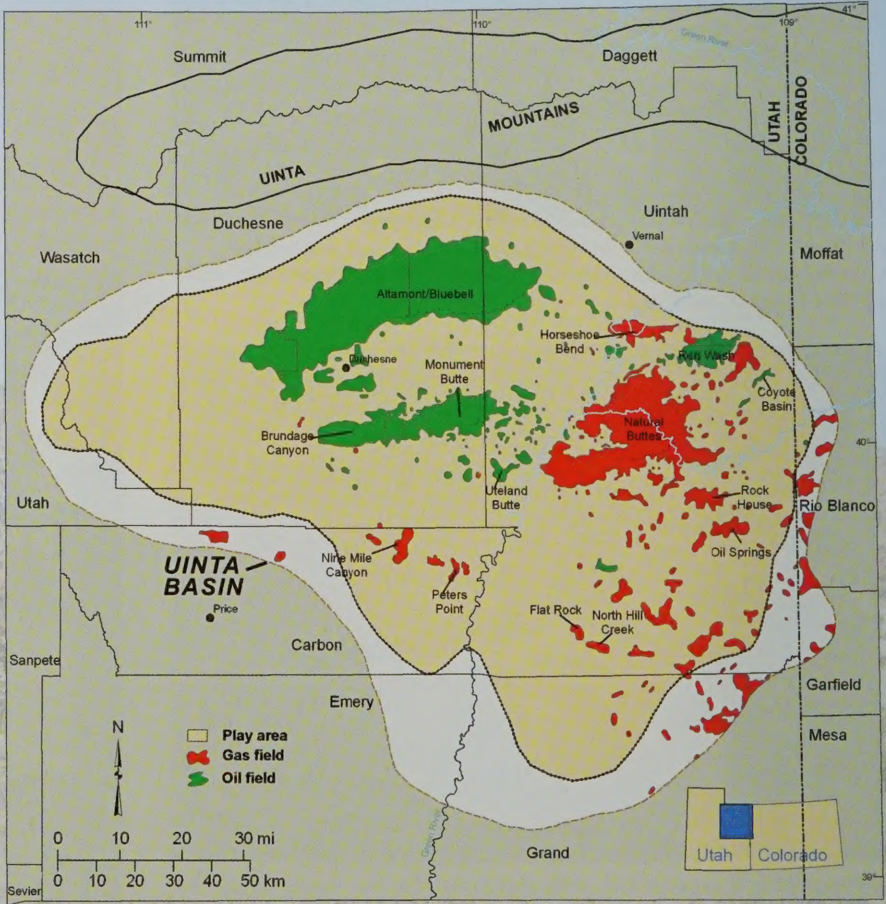


*Oil production and reserves in Utah as of January 1, 2010, showing an increase since 2002 due, in part, to the discovery of Covenant field in the new central Utah thrust belt play.*

### Utah Oil Production and Proven Reserves

Utah oil fields have produced over 1.36 billion barrels since production began in the 1940s. Although production declined from the mid-1980s to 2002, when it reached a 40-year low, the trend has since reversed. Discovery of Covenant oil field in the central Utah thrust belt ("Hingeline") play and increased development drilling in the Uinta Basin have stimulated the increased production. Among oil-producing states, Utah currently ranks eleventh in domestic oil production. There are over 200 active oil fields in Utah.

Despite over 40 years of production at rates that have varied by a factor of three, Utah's proven oil reserves during this time have remained above 200 million barrels, indicating significant oil remains to be produced. As of 2009, proven reserves are relatively high, at 355 million barrels. With higher oil prices now prevailing, state-of-the-art horizontal drilling and secondary and tertiary recovery techniques should boost future production rates and ultimate recovery from known fields.

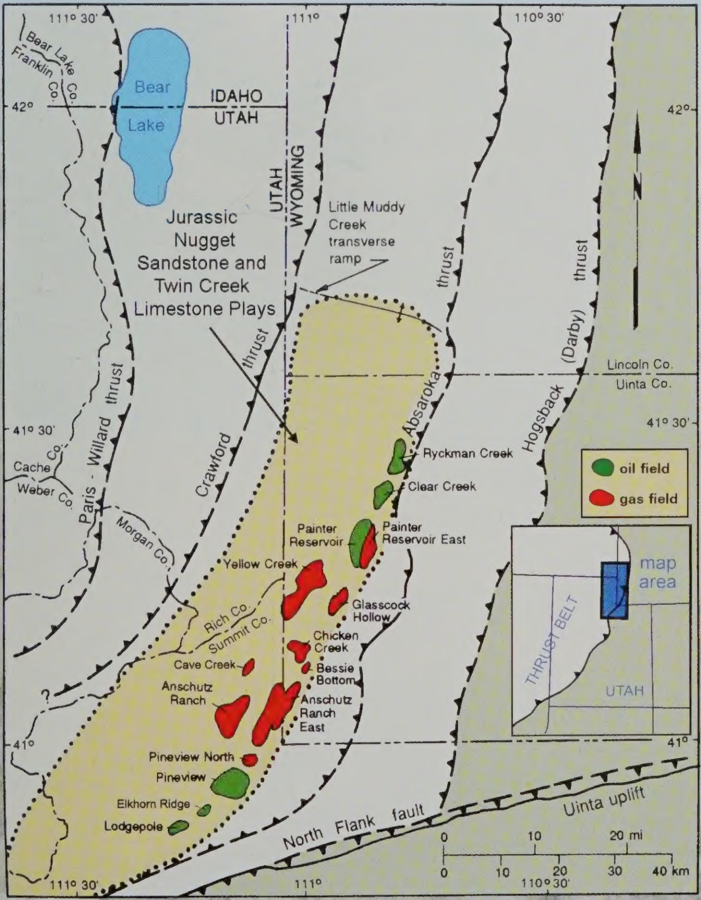


*Oil and gas fields in the Uinta Basin of Utah and Colorado. Significant amounts of bypassed oil in many of the basin's fields could be produced using special well-evaluation and stimulation techniques.*

### Potential Increased Recovery/ New Technology

While Utah still contains large areas that are virtually unexplored, there is also

*Oil and gas fields in the Paradox Basin of Utah, Colorado, and Arizona. New regional subsurface maps, evidence of deep hydrothermal activity, and innovative exploration methods suggest large areas of untested oil potential.*



*Oil and gas fields, uplifts, and major thrust faults (sawteeth) in the Utah-Wyoming thrust belt. Future exploration could focus on more structurally complex and subtle, thrust-related traps using 3-D seismic surveys with any new fields developed by horizontal drilling.*

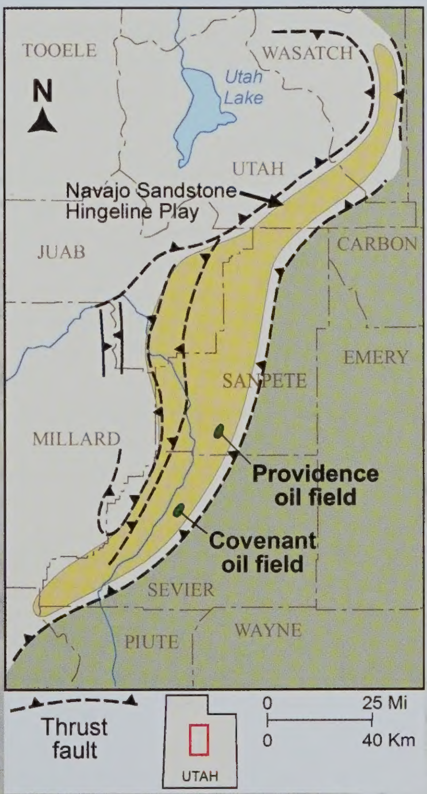
significant potential for increased recovery from existing fields by improved understanding of reservoir (the oil-producing rock layers) characteristics and use of the latest drilling, well-completion, and secondary/tertiary production technologies. New exploratory targets may be identified and better defined using advanced technologies such as three-dimensional (3-D) seismic surveys or soil-gas surveys. Development of potential prospects is within the economic and technical capabilities of both major and small independent companies.

## New UGS Study

The new UGS study will help increase recoverable oil reserves from existing field reservoirs and new discoveries by providing play portfolios for the major oil-producing provinces. The play portfolios include the following descriptions: (1) tectonic setting, (2) reservoir stratigraphy, thickness, and rock types (lithology), (3) type of oil traps, (4) rock properties, (5) oil and gas chemical and physical characteristics, (6) source rocks including timing of generation and migration of oil, (7) exploration and production history, (8) case-study oil field evaluations, (9) summaries of the state-of-the-art current and potential best drilling, completion, and production practices, and potential for new secondary/tertiary enhanced oil recovery, (10) descriptions of reservoir outcrop analogs for each play, (11) exploration potential and trends, and (12) maps of the major oil plays and subplays.

## Significant Findings

- The 2004 discovery of the 100-million-barrel Covenant field in the central Utah thrust belt changed the oil development potential of the Jurassic (176 million years) Navajo Sandstone Hingeline play from hypothetical to



*Location of Covenant and Providence oil fields, uplifts, and selected thrust systems in the central Utah thrust belt. Numerous structures in the region have untested oil potential.*

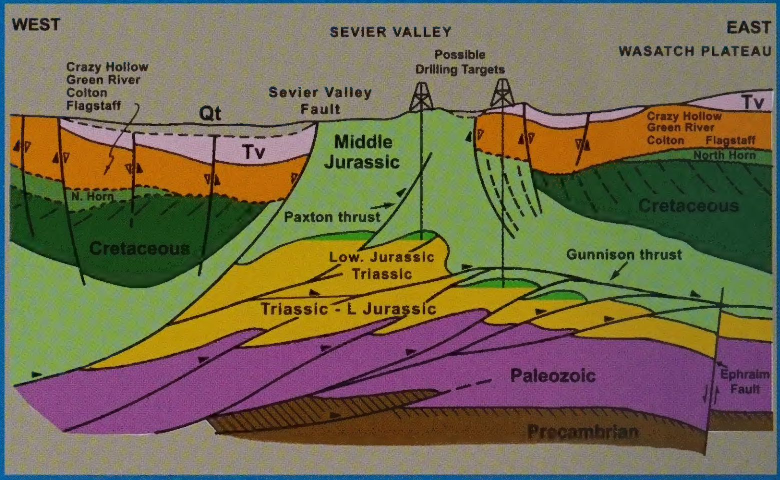
proven (another field, Providence, was discovered in 2008). Deep, Paleozoic-cored thrust structures (folds developed along low-angle faults where older rocks have been pushed over younger rocks) represent numerous future drilling targets.

- The best reservoir properties associated with the Mississippian (340 million years) Leadville Limestone Paradox Basin play were developed during late (34 million years), deep subsurface hydrothermal activity. Relatively low-cost surface geochemical surveys, hydrodynamic analysis, and other innovative techniques can identify potential Leadville hydrocarbon migration patterns and oil-prone areas in this environmentally sensitive region.
- Mapping the environments in which the reservoir rocks were deposited in the Paradox Formation (Pennsylvanian age—308 million years) play delineated very prospective trends in the Paradox Basin that may contain untested, ancient reef-like and Bahamas bank types of carbonate buildups that are potential hydrocarbon traps.
- In the Uinta Basin, the current production practices in several oil plays will leave a significant amount of oil unproduced in older wells. Special cased-hole well logs can identify by-passed oil in individual beds (40 or more in many wells). These beds can then be selectively stimulated to recover additional oil.
- Utah has numerous production-scale outcrop analogs that provide an excellent view of reservoir properties, environment of deposition, and lateral and vertical changes in these characteristics for each oil play. They can be used as a "template" for evaluation of data from rock core taken from wells, geophysical well logs, and seismic surveys, and the development of reservoir models for field development.

## Who Benefits from the Study?

The Utah play portfolios in this study provide a comprehensive geologic, engineering, and geographic reference to help petroleum companies plan exploration, land-acquisition strategies, and field development. These portfolios can also help pipeline companies plan future facilities and pipelines. Other potential users of the portfolios include petroleum engineers, petroleum land specialists, landowners, bankers and investors, economists, utility companies, manufacturers, county planners, and numerous government resource management agencies.

The UGS plans formal publication of this study in the near future. Contract quarterly reports are available on the UGS project Web site geology.utah.gov/emp/pump/index.htm.



*Schematic east-west structural cross section through Sevier Valley within the Hingeline area showing potential drilling targets in folds created by stacked thrust faults. Modified from Villien and Kligfield, AAPG Memoir 41, 1986.*

*Soil sampling for geochemical analysis in the Lisbon field area of the Paradox Basin. Geochemical surveys analyze soil samples for trace amounts of hydrocarbons that have naturally seeped to the surface from undiscovered oil traps.*

*The Jurassic Nugget/Navajo Sandstone was deposited in an extensive dune field that extended from Wyoming to Arizona. Outcrop analogs for thrust belt oil fields are found in the Navajo which display large-scale dunal cross-strata in sandstone with excellent reservoir properties. Example outcrop is along Lake Powell in Glen Canyon National Recreation Area.*

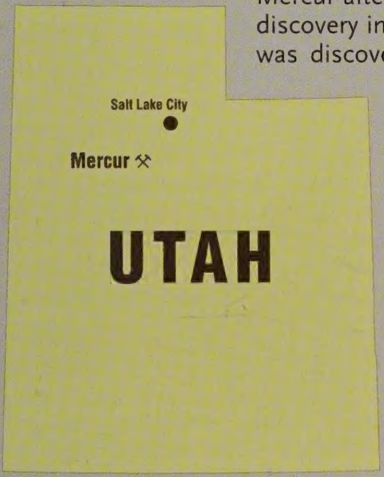
# THE MERCUR DISTRICT

## A HISTORY OF UTAH'S TOP GOLD CAMP

*by Ken Krahulec*

Historically, most gold has been produced from veins, placers, or as a by-product from base metal mines. However, in the early 1960s a new type of gold deposit was recognized at Carlin, Nevada. These Carlin-type sedimentary-rock-hosted gold deposits are unique in that the gold occurs primarily as microscopic particles disseminated in dark-gray to black, platy, carbonaceous, silty limestone. The gold grains are too small to see with the naked eye or even a magnifying hand lens (generally less than 0.0002 inch across), and eroding gold deposits do not form placers that a prospector could identify in the field. What was not recognized until 1968 is that the gold deposits at Mercur, Utah, which had been successfully mined in the 1890s, also belong to the Carlin deposit type.

The Mercur mining district lies on the southwestern flank of the Oquirrh Mountains in eastern Tooele County. The district was originally organized in 1870, and the initial production was from high-grade silver pockets. However, this early boom quickly faded and the camp was reorganized and renamed Mercur after a cinnabar (mercury sulfide) discovery in 1879. In 1883, a "gold ledge" was discovered, but the gold could not be recovered economically (because the grains were too small to concentrate) until the mine began using the "new" cyanide process in about 1890. In 1897, the 1000-ton-per-day Golden Gate mill at Mercur was the largest cyanide mill in the U.S., and it operated very successfully until about 1913 when decreasing gold grades from the mine made the operation unprofitable.



The history of the Mercur camp is enriched by a couple of important figures who were there during this 1890 to 1913 boom period. George H. Dern was general manager and superintendent of the Mercur Gold Mining and Milling Company and later the Consolidated Mercur Gold Mines Company. Dern went on to positions with mining companies in the Park City, Tintic, and Little Cottonwood mining districts before becoming the two-term governor of Utah from 1924 to 1933. Daniel C. Jackling was the metallurgical and construction superintendent of the Golden Gate mill, which was one of the first successful cyanide mills in the U.S. After his success at Mercur, Jackling (1) was a founder of the Utah Copper Company (Bingham), (2) became president of Kennecott Copper Company, (3) was recognized as the "father" of open pit copper mining, (4) developed the "Jackling porphyries" in Utah, Arizona, New Mexico, and Nevada, and (5) was inducted into the National Mining Hall of Fame.

Production from the Mercur district after 1913 was minor and intermittent until continuous gold production resumed with increased gold prices from 1933 until 1942. Then the U.S. government closed all gold mines (Order L-208) to conserve manpower and materials for World War II. Following the brief mining of some silver-rich silica flux for the Garfield copper smelter at the north end of the Oquirrh Mountains, production in the Mercur district ceased again in 1945.

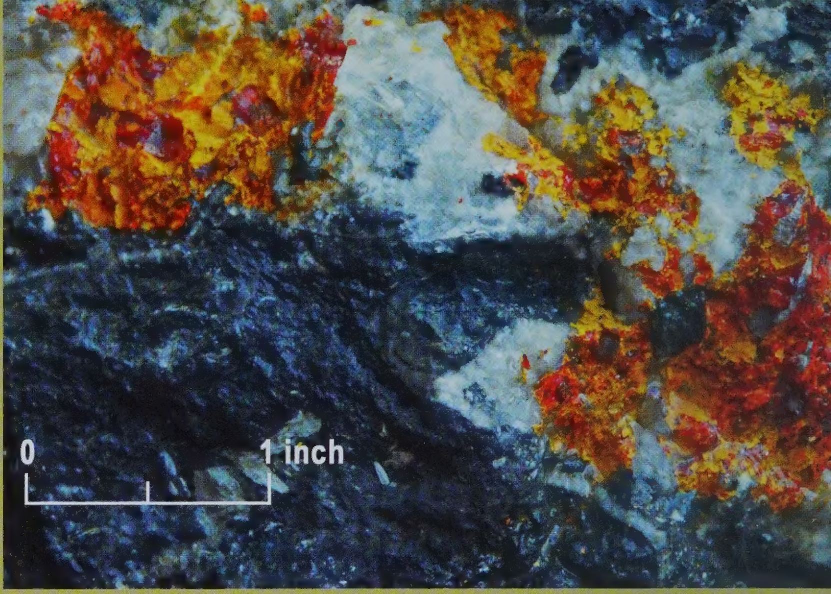
In 1968, Newmont Mining Corporation recognized the similarity of Mercur to their Carlin gold mine, indicating that Mercur was a Carlin-type deposit. They acquired the old Marion Hill and Sacramento mines as well as adjoining areas in the southern part of the Mercur district. Newmont drilled a series of unsuccessful exploration holes before dropping their interest in the district. Gold Standard, Inc., then consolidated the major land holdings in the central part of the district in the early 1970s, including some property owned by Charlie Steen, Utah's uranium king, and sold the property to Getty Oil Company in 1973. Getty revived production in the old camp, following the escalating gold price, in 1983 with a large open pit mine–heap leach operation. Barrick Gold Corporation acquired the mine in 1985, an autoclave was added in 1989 to improve gold recovery, and the mine produced over 100,000 ounces of gold per year until 1995 when the economic reserves were exhausted. Currently, the mines are nearly completely reclaimed.

The Mercur gold ores are largely confined to a sequence of black, thin- to medium-bedded, carbonaceous, fossiliferous, and iron-

*Panoramic view of the Mercur district, looking southeast, in the early 1900s (from The Ore Deposits of Utah, 1920).*

rich limestone, calcareous sandstone, calcareous siltstone, and shale. Most of the mineralization in the Mercur district is concentrated near the crest of the Ophir anticline and localized near an east-northeast-trending set of normal faults. The most obvious alteration associated with the gold ores in the Mercur district is the extensive silicification (jasperoid) at the base of the Mercur member. The individual gold deposits occur as lenses associated with the destruction of carbonate minerals (decalcification) and clay alteration of the limestone host rocks above this basal jasperoid. The most common minerals associated with the gold ore are pyrite, marcasite, orpiment, realgar, barite, stibnite, cinnabar, and a few very rare thallium minerals.

The Mercur district ultimately produced about 2.5 million ounces of gold, making it Utah's largest primary gold mining district, despite the fact that no gold was ever recognized in hand specimen. The price of gold during the years Mercur was recently in production ranged from under $300 to about $450 per ounce. It is too early to tell if the current $1000 per ounce gold price will again revive the original sedimentary-rock-hosted gold mines at Mercur.



*Sample of Mercur gold ore showing orpiment (orange), realgar (red), and calcite (white) in dark gray limestone.*

# SURVEY NEWS

## EMPLOYEE NEWS

**J. Wallace Gwynn** retired after 34 years with the UGS. His doctoral dissertation was on the tar sand deposits of the Sunnyside area, and he continued research on the tar sand resources of Utah. However, most of his studies focused on Utah's saline resources, particularly Great Salt Lake, but also the saline resources of Sevier Lake and the bedded deposits of the Paradox Basin. He edited two comprehensive volumes on the scientific, historical, and economic aspects of Great Salt Lake, and helped the Department of Natural Resources in the formulation of a management plan for the lake. Wally's knowledge and expertise will be missed.

**Bryce Tripp** also retired from the UGS after 30 years of service. His work focused on the industrial mineral resources of Utah, particularly limestone, zeolites, potash, building stone, and sand and gravel, but he also investigated Utah's tar sand deposits. Bryce was instrumental in establishing the Utah Mineral Occurrence System database and getting it converted from the original paper files to digital form. We wish Bryce well in his retirement!

The Geologic Hazards Program bid farewell to **Francis Ashland** who accepted a position with the U.S. Geological Survey in Reston, Virginia. Best of luck, Francis, in your new endeavor.

The Utah State Energy Program (USEP) has hired additional staff with funding from the American Recovery and Reinvestment Act. **Jerriann Ernsten** has a Ph.D. in biology (Utah State University), **Alex Dalphé-Charron** has an M.S. in Environmental Policy (University of Utah), and **Chris Tallackson** has an M.P.A. in Public Administration (University of Utah). Also joining USEP is **Larry Hendrick**, who has a B.S. in Computer Science, and **Deborah Boren**, who accepted the secretarial position and has worked in the private sector for 20 years.

The Ground Water and Paleontology Program welcomes geologist **Paul Inkenbrand**. Paul has an M.S. from Utah State University in hydrology/ground water.

*continued on page 11...*

# TEACHER'S CORNER

## Earth Science Week Returns!

After last year's activities at the UGS were canceled due to building renovation, Earth Science Week is back and so are the teachers and students. In October of this year, 680 excited students descended on the UGS to celebrate Earth Science Week.

School classes, some having as many as 100 students, were divided into five groups, which then rotated through five 15-minute activity stations. The activities included panning for gold, observing stream erosion and deposition, identifying rocks and minerals, and learning about dinosaur fossils.

Thanks to the many volunteers from various agencies and organizations, the week was a success. We were pleased to see participants gain a better understanding and appreciation for the Earth sciences, which has been the mission of Earth Science Week since its inception in 1998 by the American Geological Institute. The methods we use to accomplish this mission—engaging students in discovering the Earth sciences, reminding people that Earth science is all around us, and motivating geoscientists to share their knowledge and enthusiasm about the Earth—appear to be effective!

# LEGISLATIVE DIRECTIVES TO THE UTAH STATE ENERGY PROGRAM 2009

*by Elise Brown and William Chatwin*

When the gavel falls on the final day of the Utah Legislative General Session, much of the work is just beginning on bills that have passed into law. If there are energy implications of new laws, frequently the Utah Geological Survey's Utah State Energy Program (USEP) has a role in bringing the legislature's intentions to fruition.

The 2009 General Session resulted in two legislative actions that required USEP's assistance to implement. First, Senate Joint Resolution 1 specifically tasked the USEP to examine and develop model renewable energy ordinances. Second, Senate Bill 211 changed the way Utah adopts building codes by vesting the ultimate decision with elected officials. The USEP coordinated with the Utah Uniform Building Code Commission (UBCC) to conduct an analysis of changes to the International Energy Conservation Code (IECC).

## MODEL RENEWABLE ENERGY ORDINANCES

Senate Joint Resolution 1 charged the USEP with holding consensus-building stakeholder meetings to produce model wind, solar, geothermal, hydroelectric, and biomass ordinances, as the USEP deems necessary. Emerging technologies, such as renewable energy systems, are often uncharted territory for local planners. As a result, the permitting process can be cumbersome for energy developers and governments alike. The purpose of model ordinances is to provide a template that cities and counties may consider when writing local rules and regulations.

The USEP found wind and solar to be important to examine. Through the ongoing functions of the Wind and Solar Working Groups and Resource Development Coordinating Committee, stakeholder comments were gathered. Interested parties such as the League of Cities and Towns, city and county planners, environmental groups, utilities, and others were invited to participate. The model wind ordinance provides language for both large and small wind developments that can be adopted with or without modification by cities and counties. The initial feedback the USEP gathered from the Solar Working Group suggests that a model ordinance may not be as helpful to city and county planners as a list of topics and questions pertaining to solar. This list, like the wind ordinance, will function as a tool for planners to help ensure that they address possible conflicts that may arise if a solar ordinance is passed.

Regarding other renewable energy sources, the USEP and stakeholders determined that model ordinances are unnecessary at this time. Utah's leading geothermal electricity developers have all agreed that processes are already in place for their developments. Hydroelectric developments require water permits and may also necessitate a building permit from the local jurisdiction. Hydroelectricity is rarely installed on a residential scale in Utah, and thus is unlikely to require a local government ordinance. Biomass or bioenergy varies dramatically from installation to installation, and there are very few in Utah. As such, a unified code on a city or county level would not be helpful; these types of systems are better assessed for permitting on a case-by-case basis.

## ENERGY CODE ANALYSIS

For the past 20 years, the code adoption process in Utah has been accomplished through administrative rule changes proposed by the UBCC. Utah updated all of its building codes on a regular interval that coincided with the publication of new national or international building codes. During the one-year lag between publication of the new codes and adoption in Utah, the UBCC would analyze the upgraded codes and possible amendments through their group of six advisory committees. Any interest groups who opposed provisions of the new codes were obligated to propose amendments through an explicit process within the advisory committees.

Following controversy about how codes are developed at the national level, Utah passed Senate Bill 211 to increase accountability for adoption of all state-level building codes, including the IECC. The change requires a legislative act for adoption, involving more layers of political process than for an administrative rule change. Additionally, there are two other main implications. First, the State Legislature requested more industry input to identify controversial provisions in the new codes. Second, the burden of proof has been shifted to proponents of upgraded codes to justify why Utah ought to adopt, rather than opponents making proposals for amendments.

Over the past several years the USEP has administered free energy code training that has included technical assistance for timely responses to code clarifications. This technical assistance was invaluable for quantifying the benefit to the State from adopting upgraded energy codes. We worked closely with our energy code trainer to conduct computer simulations showing the annual energy savings of different types of houses built to the proposed code upgrade. We also worked with other partners to illustrate different types of benefits and costs. For example, positive cash flow analysis shows the threshold where monthly energy cost savings are more than the increased monthly mortgage costs for an upgraded-code house, leaving more money in the homeowner's pocket.

## CURRENT STATUS AS OF FALL 2009

The USEP reported the initial results of the model renewable ordinance process to the Utah State Legislature in fall of 2009. Stakeholder meetings for solar and wind are being held at the time of this writing, so no conclusions have yet been determined. Please see geology.utah.gov/sep/renewable_energy/index.htm for updated information on outcomes and participating parties.

The UBCC has made substantial progress in meeting the burden of proof for adopting upgraded energy codes. After numerous UBCC, advisory committee, and industry ad hoc meetings, a recommendation was made to adopt the upgraded provisions for commercial buildings and to conduct further analysis of the residential provisions (to be completed by June 30, 2010). The Legislature's Business and Labor Interim Committee has voted to forward a draft bill into the General Session setting the stage for the Legislature to formalize adoption. That is, until the UBCC completes the residential analysis and generates additional recommendations. ■

# GLAD YOU ASKED

## WHAT ARE THOSE LINES ON THE MOUNTAIN?
### FROM BREAD LINES TO EROSION-CONTROL LINES

*by Mark Milligan*

Sometimes I get a public inquiry that leads to a "Glad You Asked" article, and sometimes I see something interesting in the field and wish I would get a question about it. This time it was a case of the latter. A gentleman called and asked, "What are the lines up on the side of the mountain?" Along the Wasatch Front we have fault lines, shorelines, lines from rock layers (bedding planes), lines formed by volcanic dikes, and lines formed by other natural phenomena. The caller gave a location for the lines that was above the elevation of the Wasatch fault zone and the highest shoreline of ancient Lake Bonneville. He described sets of lines that marched up the mountainside, nearly horizontal and regularly spaced. Bedding planes, perhaps? No, these lines were not a feature of exposed bedrock but rather rocky soil. Ah ha! I had previously seen such features along the Wasatch Front and elsewhere in Utah and discovered they are not a natural feature. These "lines" are erosion control terraces dug by machines and men of the Civilian Conservation Corps (CCC).

The Great Depression had hit Utah particularly hard. By 1932, wages for those Utahns who had not lost their jobs had declined by 45 percent. While the nation's unemployment rate peaked in 1933 at a whopping 25 percent, Utah's unemployment rate peaked at 36 percent, the fourth highest in the nation. The unemployed and dispossessed first turned to private charities and local governments for relief, but the demand was too great, and it was the federal government that provided the bulk of needed aid. By the spring of 1933, 32 percent of Utahns were receiving government relief. During the 1930s, for every dollar Utahns sent to Washington, D.C., in taxes, Washington sent $7 back. Much of this spending was in the form of New Deal programs of the Franklin D. Roosevelt administration.

The CCC was a prominent New Deal agency in Utah. The Utah CCC worked on a wide range of conservation projects including dam and canal building, range reseeding, infrastructure improvements in national and state parks, and erosion-control projects such as the construction of the "lines" found on Wasatch Front and other Utah mountainsides. Beginning in May 1933 and lasting for over nine years, the CCC opened a total of 116 camps in Utah, with 30 to 35 operating at any given time. Across 27 of Utah's 29 counties, 22,074 Utah men plus 23,833 men from out-of-state worked on Utah projects— large numbers, especially considering Utah's labor force had only reached 181,244 by the 1940 census. Men of the CCC received room, board, and $30 a month, of which they could keep $5 to spend on themselves while the remaining $25 was mailed to their families (adjusted for inflation that equates to about $480, $80, and $400, respectively).

Debris flows have impacted Wasatch Front cities and towns since pioneer settlement. With increased development and poor watershed management, numerous damaging episodes occurred between 1912 and 1930. Davis County was particularly hard-hit by these disasters where multiple flood and debris-flow events in 1912, 1923, and 1930 caused major damage to houses, roads, and other infrastructure. Seven people died in the 1923 Farmington Canyon debris flow, making it one of Utah's deadliest. All of these debris flows were triggered by intense summer thunderstorms on steep slopes denuded of vegetation by fire, overgrazing, and to a lesser extent logging. With little vegetation to promote water infiltration and hold soil and rock in place, the runoff flowed downslope, eroding soil. When this surface water flowed into gullies and stream channels its erosive power increased and scoured the channels of stored sediment, which was then transported and deposited beyond the canyon mouths, causing damage and loss of life. Although stream channels provided most of the sediment in these destructive debris flows, the process started with mountainside erosion.

*Homes damaged by a 1930 debris flow in Centerville below the mouth of Parrish Canyon (top) and unknown location (bottom), Davis County. Photos courtesy of the J. Willard Marriot Library.*

*Laborers from the CCC Hobble Creek Camp constructing erosion-control terraces (left) and completed terraces (right). Location unknown but presumably in Utah County near Springville and the Hobble Creek drainage basin. Photos courtesy of the Utah Historical Society.*

*Recent photo of erosion-control terraces constructed by the CCC in the 1930s, above the Bonneville shoreline in North Salt Lake, Davis County.*

In response, the CCC was put to work on erosion-control projects that included mountainside contour terracing along the Wasatch Front and elsewhere. The terracing consisted of horizontal trenches dug across the slope such that they would catch or slow surface runoff and allow water infiltration into the soil, thereby limiting erosion. Contour terracing with reduced grazing appears to have been effective, as evidenced by the small number of debris flows between 1935 and 1982. However, in the spring of 1983 and 1984, record rainfall and rapid snowmelt saturated soil on steep mountainsides and caused small landslides that transformed into debris flows that charged down gullies and stream channels all along the Wasatch Front. Thus, reducing the risk of damaging debris flows in complex natural systems remains a challenge, even in areas with erosion-control measures.

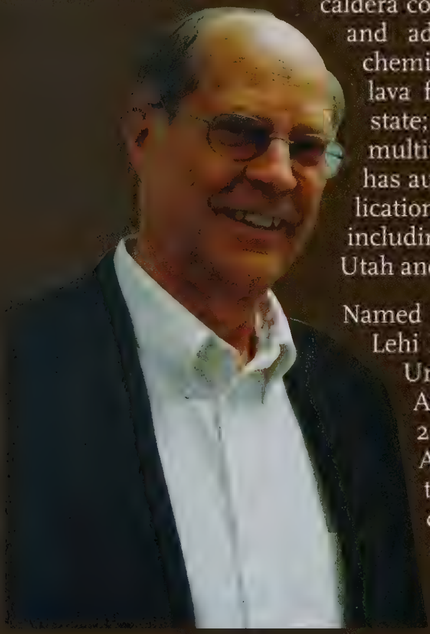
# SURVEY NEWS

continued from page 8...

## 2009 LEHI HINTZE AWARD

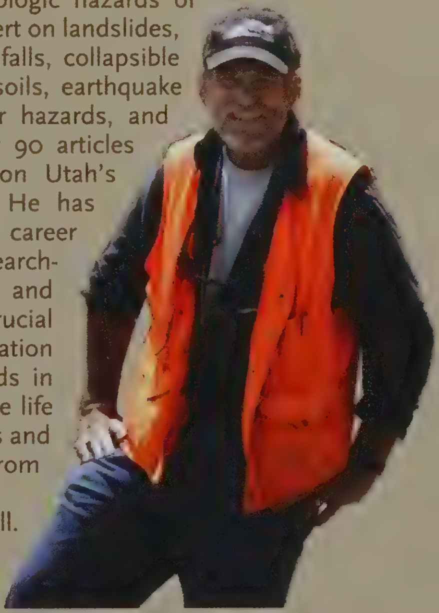
The Utah Geological Association and the Utah Geological Survey presented the 2009 Lehi Hintze Award to Myron G. Best, emeritus Professor of Geology, Brigham Young University. Myron has devoted much of his 50-year career to sorting out the volcanic and tectonic history of Utah. He has discovered and named a series of large ignimbrites (pyroclastic flow deposits) and their associated caldera complexes in southern Utah and adjacent Nevada; mapped, chemically analyzed, and dated lava flows across much of the state; and provided training to a multitude of geologists. Myron has authored more than 50 publications of the geology of Utah, including many geologic maps of Utah and adjacent areas of Nevada.

Named for the first recipient, Dr. Lehi Hintze of Brigham Young University, the Lehi Hintze Award was established in 2003 by the Utah Geological Association and the UGS to recognize outstanding contributions to the understanding of Utah geology.



## 2009 GOVERNOR'S MEDAL FOR SCIENCE AND TECHNOLOGY

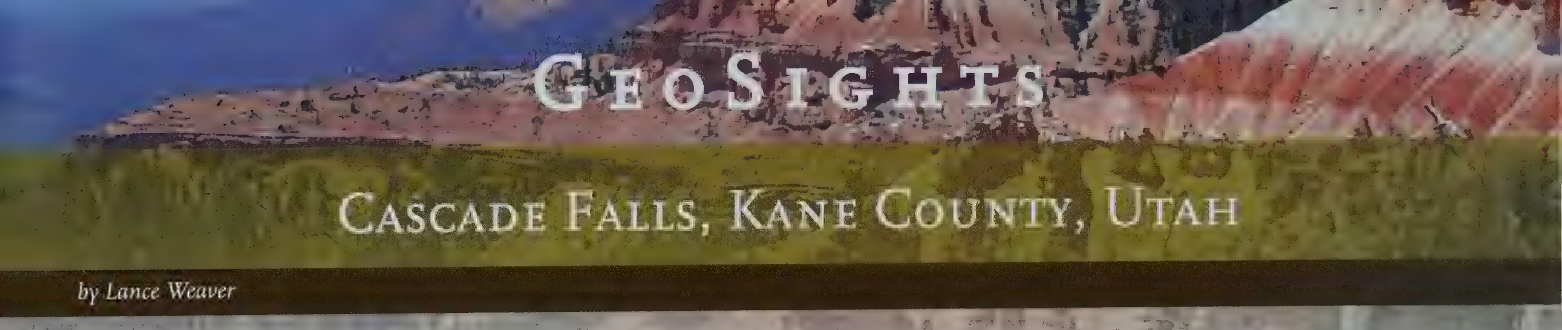
Bill Lund was awarded the Governor's Medal for Science and Technology for his scientific contributions in the field of geologic hazards of Utah. Bill is an expert on landslides, debris flows, rock falls, collapsible soils, expandable soils, earthquake faulting, and other hazards, and has authored over 90 articles and publications on Utah's geologic hazards. He has spent his 30-year career with the UGS researching, documenting, and disseminating crucial scientific information on geologic hazards in Utah, to protect the life safety of its citizens and reduce the risk from geologic hazards. Congratulations, Bill.



# GEOSIGHTS

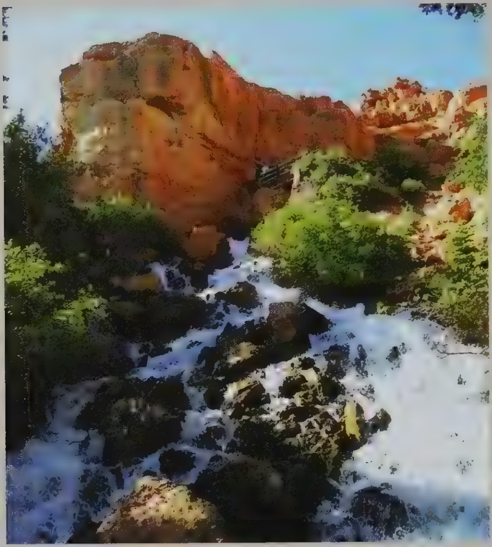
## CASCADE FALLS, KANE COUNTY, UTAH

*by Lance Weaver*

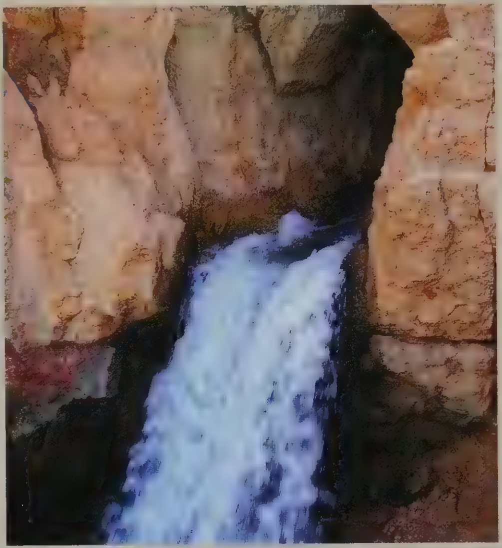


*The Pink Cliffs escarpment at the southern margin of the Markagunt Plateau viewed from the Cascade Falls Trail.*

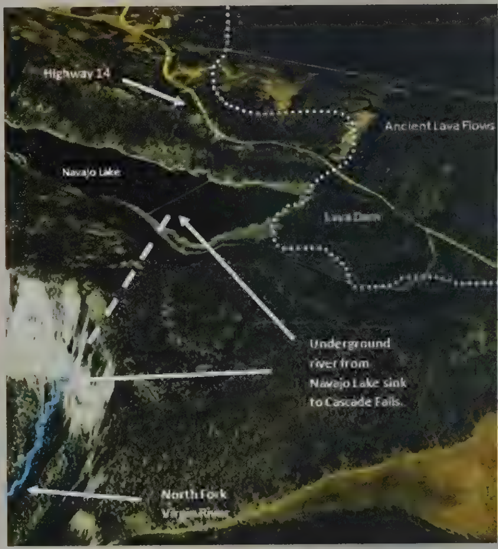
Nestled in the northwestern corner of Kane County is a geologically unique feature that receives relatively few visitors. Although most people in Utah have seen caves and waterfalls, it is peculiar for a waterfall to emerge from a cave system. Cascade Falls does just that, as an underground river emerges from a deep cave system and cascades down a steep cliff face. The cave system is the product of sinkholes within the water-soluble rocks of the Claron Formation of the Markagunt Plateau. This incredible cascading waterfall first formed when an ancient lava flow dammed the drainage in a narrow valley, creating Navajo Lake. Water from this lake found its way through the water-soluble marl (freshwater limestone) of the Claron Formation, eventually forming a cave system that extends a little over a mile from below the southeastern end of Navajo Lake to the Pink Cliffs escarpment at Cascade Falls.



*Cascade Falls just below the cave opening, forming the headwaters of the North Fork of the Virgin River.*



*Cascade Falls as it emerges from the limestone cave system of the Claron Formation.*

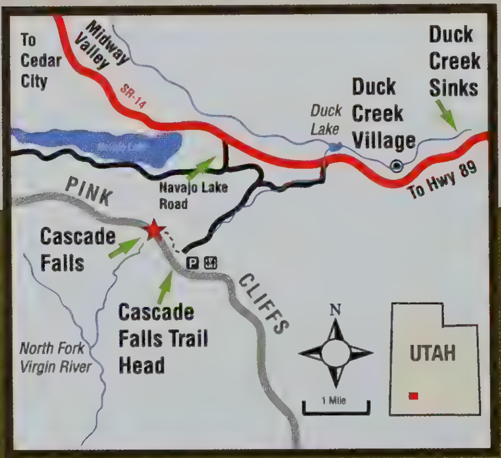


*Oblique aerial view taken from Google Earth looking northwest over Cascade Falls and Navajo Lake.*

Depending on the level of Navajo Lake, the waterfall can range from a small trickle to a raging torrent. During dry years, Navajo Lake is kept from completely draining into the sinkhole that feeds Cascade Falls by an engineered earthen dam. In wet years, however, when the lake inundates the small dam and fills the entire valley, the sink acts like a bathtub drain, allowing lake water to flow southward through the underground cave system and emerge at Cascade Falls as the headwaters of the North Fork of the Virgin River. When the lake level is low enough for the dam to be exposed, the overflow can be seen draining into the cave system through a small opening in the bottom of the sinkhole.

Sinkholes, also known as sinks, are depressions caused by the collapse of subterranean caverns, often formed by the dissolution of water-soluble rocks such as limestone or marl. Sinkholes and collapse features are common within the Claron Formation of the Markagunt Plateau and can be seen in abundance along State Highway 14 between Midway Valley and the Duck Creek Sinks. Navajo Lake itself is fed by numerous springs along its western margin that are likely recharged by snowmelt flowing into sinkholes in adjoining Deer Valley.

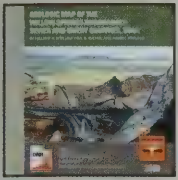
The distinctive Claron Formation is the same geological layer that forms the picturesque towers and hoodoos of Bryce Canyon National Park and nearby Cedar Breaks National Monument. The rocks of the lower part of this formation were deposited on a broad alluvial plain with shallow lakes and ponds around 50 million years ago, during the Paleocene and Eocene Epochs. The formation contains alternating layers of limestone, marl, calcareous sandstone, and minor conglomerate; the layers are vividly colored orange, red, pink, and white by a combination of sediment composition, weathering (oxidation) of iron-bearing minerals, and soil-forming processes. ■



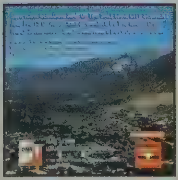
### How to get there:

Cascade Falls is located in southern Utah, just south of State Highway 14. Highway 14 can be accessed from I-15 in Cedar City on the west or from U.S. Highway 89 at Long Valley Junction on the east. To get there from I-15 and Cedar City, head 27 miles east on Highway 14. After passing the Navajo Lake scenic pull-out with its descriptive signs, turn right (south) on the road to the lake. After 0.4 mile, the road splits. The right fork goes on to the Navajo Lake boat docks and lodges, and the left fork goes approximately three miles (stay right at the "Y" junction to Duck Creek) to the Cascade Falls overlook and trail parking lot. The trail to the falls is approximately 1/2 mile one way.

# NEW PUBLICATIONS

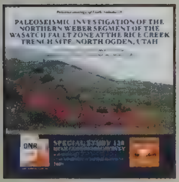


Geologic map of the Willow Springs quadrangle, Sevier and Emery Counties, Utah, by Hellmut D. Doelling, Paul A. Kuehne, and James I. Kirkland, CD (14 p., 2 pl., 1:24,000), M-237 ........ $14.95



Surficial geologic map of the Salt Lake City segment and part of adjacent segments of the Wasatch fault zone, Davis, Salt Lake, and Utah Counties (digitized from U.S. Geological Survey Miscellaneous Investigations Series Map I-2106, 1992), by Stephen F. Personius and William E. Scott, CD (2 pl., 1:24,000 [contains GIS files]), ISBN 1-55791-821-X, M-243DM ........ $24.95

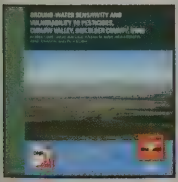
Available coal resource for the Salina Canyon and southwestern part of the Wasatch Plateau coalfields, Sevier County, Utah, by David E. Tabet, Brigitte P. Hucka, Jeffrey C. Quick, and Sharon I. Wakefield, CD (17 p. + 14 p. appendix), ISBN 1-55791-817-1, SS-129 ........ $14.95



Paleoseismology of Utah, Volume 18: Paleoseismic investigation of the northern Weber segment of the Wasatch fault zone at the Rice Creek trench site, North Ogden, Utah, by Christopher B. DuRoss, Stephen F. Personius, Anthony J. Crone, Greg N. McDonald, and David J. Lidke, CD (27 p. + 9 p. appendices, 2 pl.), ISBN 1-55791-819-8, SS-130 ........ 19.95

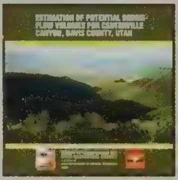
Characterization and hazard zonation of the Meadow Creek landslide affecting State Route 9, part of the Coal Hill landslide complex, western Kane County, Utah, by Francis X. Ashland, Greg N. McDonald, Lucas M. Shaw, and James A. Bay, CD (29 p. + 1 p. appendix, 2 pl.), ISBN 1-55791-822-8, SS-131 ........ $19.95

2008 Summary of mineral activity in Utah, by Roger L. Bon and Ken A. Krahulec, CD (14 p.), ISBN 1-55791-818-X, C-109 ........ $14.95

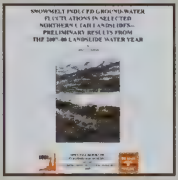


Ground-water sensitivity and vulnerability to pesticides, Curlew Valley, Box Elder County, Utah, by Mike Lowe, Janae Wallace, Stefan Kirby, Rich Emerson, Anne Johnson, and Rich Riding, CD (27 p., 2 pl.), RI-265 ........ $19.95

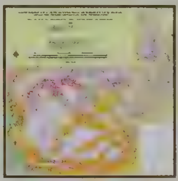
Ground-water sensitivity and vulnerability to pesticides, Beryl-Enterprise area, Iron, Washington, and Beaver Counties, Utah, by Mike Lowe, Janae Wallace, Rich Emerson, Anne Johnson, and Rich Riding, CD (28 p., 2 pl.), RI-266 ........ $19.95



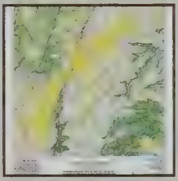
Estimation of potential debris-flow volumes for Centerville Canyon, Davis County, Utah, by Richard E. Giraud and Jessica J. Castleton, CD (14 p. + 19 p. appendix), RI-267 ........ $14.95



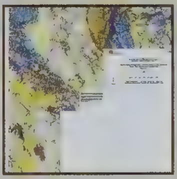
Snowmelt-induced ground-water fluctuations in selected northern Utah landslides—preliminary results from the 2007–08 landslide water year, by Francis X. Ashland, 19 p., OFR-550 ........ $8.95



Interim geologic map of the south-central part of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah—Year 1 progress report by Robert F. Biek, David W. Moore, John J. Anderson, Peter D. Rowley, L. David Nealey, Edward G. Sable, and Basia Matyjasik, 91 p., 1 pl., scale 1:100,000, OFR-553 ........ $14.95



Interim geologic map of the Yellowjacket Canyon quadrangle, Kane County, Utah, and Mohave County, Arizona, by Janice M. Hayden, 17 pg., 1 pl., scale 1:24,000, OFR-554 ........ $9.95



Progress report geologic map of the Rush Valley 30' x 60' quadrangle, Tooele, Utah, and Salt Lake Counties, Utah (year 1 of 3), by Donald L. Clark, Stefan M. Kirby, and Charles G. Oviatt, 57 p., 1 pl., scale 1:62,500, OFR-555 ........ $14.95

Interim geologic map of the Ephraim 7.5-minute quadrangle, Sanpete County, Utah, by Hellmut H. Doelling, Paul A. Kuehne, and Douglas A. Sprinkel, 35 p., 1 pl., scale 1:24,000, OFR-556 ........ $9.95

Sequence stratigraphic assessment of the Muley Canyon Sandstone and Masuk Formation, Henry Mountains syncline: Implications for understanding the Muley Canyon coal zone, by Lauren P. Birgenheier, Christopher R. Fielding, Matthew J. Corbett, Christopher Kesler, DVD (30 p. + 30 p. appendices, 7 pl. [contains GIS data]), OFR-557 ........ $24.95

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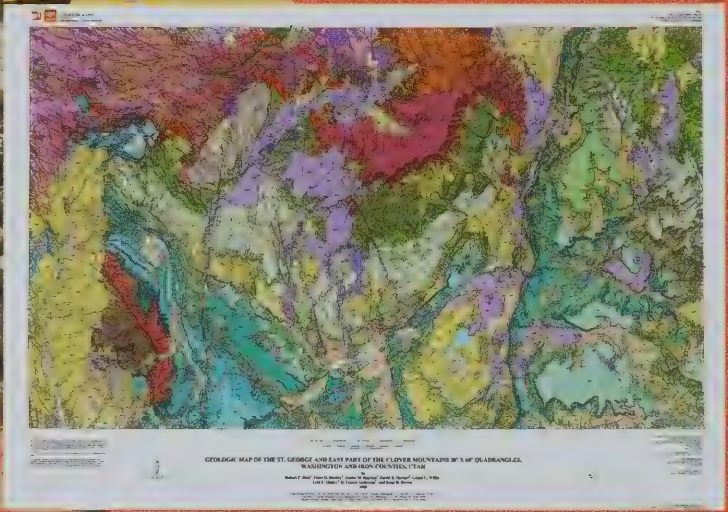
## NEW GEOLOGIC MAP OF SOUTHWESTERN UTAH



In early 2010, the Utah Geological Survey will release a geologic map of 2000 square miles in southwest Utah, comprising the St. George 30' x 60' quadrangle and the easternmost (Utah) part of the Clover Mountains 30' x 60' quadrangle. The map covers the area from the Beaver Dam and Bull Valley Mountains on the west, eastward through the St. George area to Zion National Park, and from the Arizona border north through the Pine Valley Mountains. The geologic map is one of many in our 1:100,000-scale series, where one inch on the map equals 1.6 miles on the ground.

Southwestern Utah is justly famous for its diversity of well-exposed rock formations, geologic structures and landforms, and geologic hazards and resources. Now, for the first time, this new full-color geologic map shows the regional geology in unprecedented detail. The map is accompanied by a 101-page booklet—with 68 annotated photographs and illustrations—that describes this geologically diverse and interesting region.

**Utah Geological Survey Map 242**

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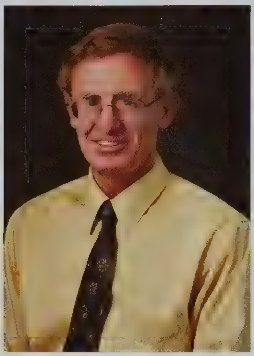
GEOLOGICAL SURVEY

# SURVEY NOTES

Volume 42, Number 2 May 2010

## HOW MANY ISLANDS ARE IN GREAT SALT LAKE?

# THE DIRECTOR'S PERSPECTIVE



by Richard G. Allis

This issue of *Survey Notes* features projects from the Ground Water and Paleontology Program. One of our largest projects in recent years has been the installation of a ground-water monitoring network in the west desert (Snake Valley) of Utah. This was specially funded by the legislature in 2007 in response to concerns that water on the Utah side of Snake Valley could be extracted by pumping on the Nevada side of the valley by the Southern Nevada Water Authority (SNWA) for use in Las Vegas. The Utah Geological Survey (UGS) spent over $3 million drilling wells and installing monitors on springs in the region (see page 6 for article by Hugh Hurlow). The wells were completed in near-surface alluvium and in basement rocks, they are located both far from and near existing irrigation areas, and the sites are spread over a 100-mile distance between Fish Springs in Juab County and northern Hamlin Valley in Millard County.

We continue to make information coming from the project available on the UGS Web site (geology.utah.gov/esp/snake_valley_project/index.htm). The interactive Google Earth map shows the various monitoring sites, and clicking on a site opens up a brief description and provides links to measurements such as the water level history, well logging data, and spring flow history. Although the monitoring history varies from as short as six months to several years, it is already clear that the hydrologic picture is not simple; some wells show declining water level trends, some show annual fluctuations, and some show stable trends. The data from the well drilling and initial monitoring are being compiled and analyzed, and we anticipate releasing the data in a UGS report toward the end of this year.

SNWA has indicated that the need for Snake Valley water has been delayed by about 10 years due to the economic downturn and slowed growth, and their applications for water rights have also been delayed by a recent decision from the Nevada Supreme Court. This delay helps with establishing the hydrologic baseline(s) in the Snake Valley area before significant new extraction of ground water occurs in the region. We believe that it could take at least 5–10 years to better understand the existing patterns of aquifer behavior and establish a scientifically sound baseline. The 2010 Utah legislature also recognized the importance of sound hydrologic data for guiding an agreement with SNWA on the allocation and management of Snake Valley ground water; it established a funding source for the UGS to maintain and monitor the wells and springs between 2010 and 2020. A priority is improving the database and its link to the UGS Web site so that everyone can see the hydrologic trends, and this can inform the decision-making process between Utah and Nevada.

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**Design:** *Stevie Emerson*

**Cover:** *Antelope Island is the largest island in Great Salt Lake. Exposures of a wide variety of rock types and ages make the island a unique outdoor geologic classroom.*

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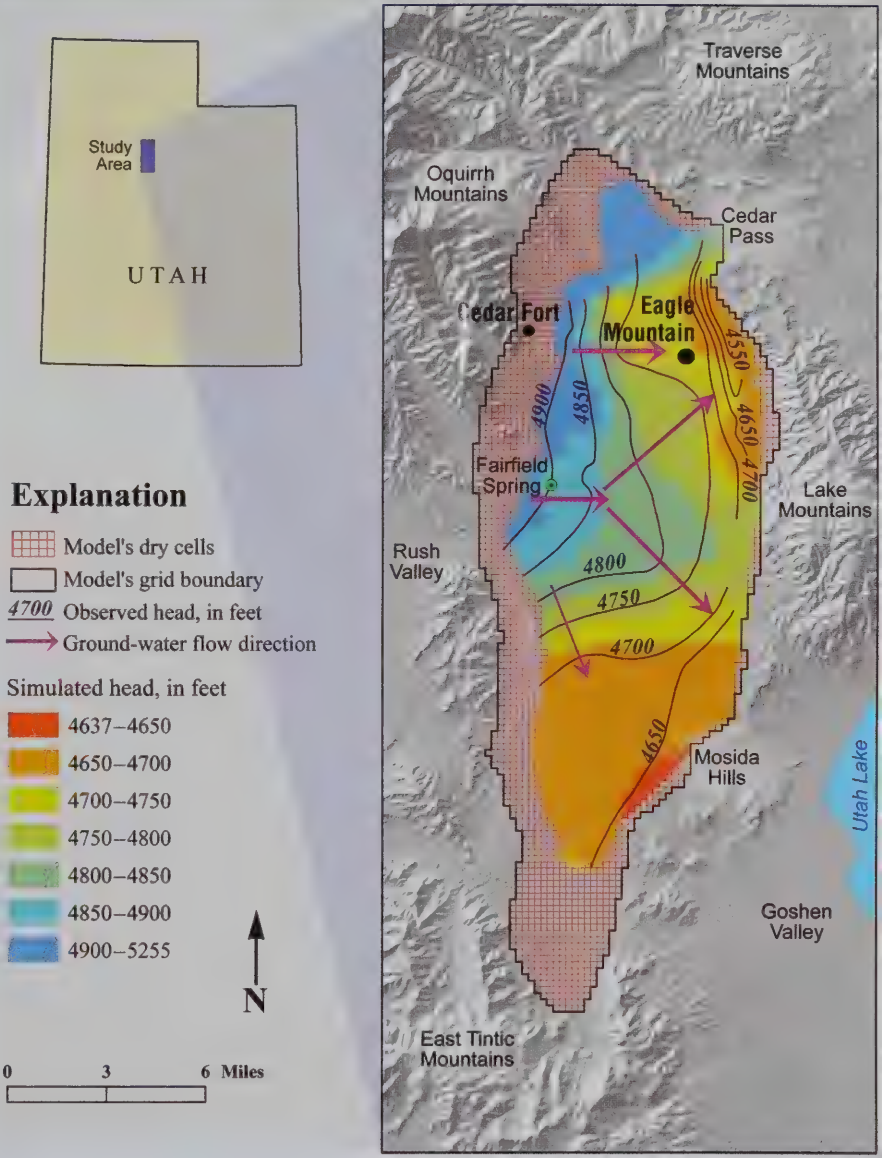
# MODELING GROUND-WATER FLOW IN CEDAR VALLEY, UTAH COUNTY

*by J. Lucy Jordan and Walid Sabbah*

The population of Utah County's Cedar Valley, including the city of Eagle Mountain, has grown from less than 1000 residents in 1990 to over 23,000 today, drastically increasing the need for potable water. This need is being met primarily by installing new wells and converting agricultural supply wells to municipal use, since the few natural streams and springs are fully appropriated. Over the past 5 years, the UGS has performed pumping tests, collected water levels and water-quality samples, and created a three-dimensional (3D) computer ground-water flow model to provide water users and regulators with a better understanding of the ground-water flow system.

Cedar Valley occupies a closed surface-water drainage basin west of Utah Lake and the Provo–Orem metropolitan area. Ground water is present in the unconsolidated sediments that fill the basin and in bedrock that underlies the basin fill and forms the surrounding Oquirrh, Traverse, Lake, and East Tintic Mountains. The unconsolidated sediments are as much as 2100 feet thick and are generally silt and clay mixed with small amounts of gravel, except near the mountains where sand and gravel dominate. A clay unit as much as 240 feet thick covers two-thirds of the surface of the valley and creates confined ground-water flow conditions beneath it. On average, the basin fill is slightly less permeable to ground water than the fractured Paleozoic carbonate bedrock, which is atypical compared to most ground-water basins.

Ground water generally flows from west to east across the valley but then encounters a north-south-trending normal fault on the eastern margin of the valley. The fault is a conduit for ground-water flow parallel to the fault, but acts as a barrier to ground-water flow across the fault. As a result, ground-water flow is directed around the Lake Mountains to exit the valley through bedrock at Cedar Pass and the Mosida Hills on the north and south ends of the Lake Mountains, respectively.



*Area of Cedar Valley ground-water model. Computer-simulated water-level elevation (colored shading) compares favorably to the measured water levels (brown contour lines) and indicates ground-water flow is from the Oquirrh Mountains across the valley to Cedar Pass and the Mosida Hills (pink arrows).*

*A shed houses a well that provides water for agricultural irrigation. Other irrigation wells have been converted to municipal supply as the population of the valley increases. Lake Mountains in the background.*

*The community of Cedar Fort sits beneath ridges of Oquirrh Group sedimentary strata, the recharge zone for aquifers underlying Cedar Valley. The population of this small town at the edge of the Oquirrh Mountains is projected to increase from around 400 to 35,000 people in the next 50 years.*

*Recent residential development in Eagle Mountain flanks the Lake Mountains in northern Cedar Valley.*

The primary source of ground-water recharge to the Cedar Valley basin-fill aquifer is mountain precipitation, which enters the basin-fill aquifer as subsurface inflow from the mountain block. We estimate mountain-block recharge ranges from 9700 to 43,800 acre-feet per year and averages 24,000 acre-feet per year (an acre-foot is the volume of water that would cover an acre of land—slightly smaller than a football field—to a depth of 1 foot). The Oquirrh Mountains likely provide about 90 percent of mountain-block recharge and the East Tintic Mountains provide the rest. Recharge through the valley floor includes seepage from one perennial stream, unused irrigation water, seasonal standing water in the center of the closed basin, a sewage treatment plant, septic tanks, and minor precipitation infiltration; these sources combined average about 1600 acre-feet per year. Based on water balance calculations and the results of our computer modeling, we think that little to no subsurface ground-water flow enters Cedar Valley from Rush Valley to the west, contrary to estimates made by other researchers in the 1960s.

Discharge out of the Cedar Valley ground-water system is primarily by subsurface flow through bedrock at the northeast and southeast margins of the valley. We estimate flow through fractured bedrock beneath Cedar Pass into northern Utah Valley is about 10,200 acre-feet per year and beneath the Mosida Hills into Goshen Valley is about 4700 acre-feet per year. Springs discharge an average of 4800 acre-feet per year, and evapotranspiration probably accounts for 3000 acre-feet per year. Discharge from wells increased from around 2500 acre-feet per year in the 1960s and early 1970s to around 5700 acre-feet per year by 2005, and then almost doubled to 10,500 acre-feet in 2007 as several large production wells came on line. Water-level trends indicate that changes in recharge due to wet and dry climatic cycles have historically had more influence on long-term ground-water levels than pumping. However, the significant increase in pumping from wells tapping the bedrock aquifer at Cedar Pass since 2005 has drawn down water levels in some wells more than can be expected as the result of climate change.

Stable and radioactive isotope analyses indicate that wells and springs along the western margin of the valley probably receive water that has traveled along flow paths a few miles in length and originating in the lower slopes of the Oquirrh Mountains, and that wells in the center of the valley likely receive recharge via long flow paths originating in the higher elevations of the Oquirrh Mountains. Water traveling along these longer flow paths may have taken hundreds or thousands of years to reach its destination. Many new wells have been drilled into bedrock in the Cedar Pass area to provide water for development. Data from these wells suggest there may be a component of modern (less than 50 years old) recharge in an otherwise quite old fractured bedrock flow system that receives its recharge from precipitation in the Oquirrh Mountains. Several bedrock wells throughout the valley produce water that is 9°F to 21°F warmer than the rest of the wells in the valley. The geologic setting of the warm-water wells and their chemical and isotopic signatures suggest deep circulation along long flow paths that end at fracture zones, which provide relatively rapid flow to near-surface wells.

UGS geologists created a 3D computer model using MODFLOW 2000 computer code to simulate ground-water flow in the basin fill during the years 1969 to 2007. The two-layer model includes an upper basin-fill layer and a lower bedrock layer, which acts only as a source of recharge and discharge in the model. The model was calibrated to match measured water levels in wells and measured flow at Fairfield Spring, the valley's largest spring. We modeled a variety of possible scenarios, including drought and increased pumping, 30 years into the future. If 2007 pumping and average climatic conditions persist, the model predicts most areas of the basin-fill aquifer will experience as much as 15 feet of drawdown from 2007 levels. In scenarios that include doubling the 2007 well extraction rates, large areas of the valley are predicted to experience over 100 feet of drawdown, and the northeast corner of the valley, where recent bedrock wells have been developed for municipal use, generally would experience even greater amounts of drawdown.

Our study is providing new insight into the ground-water resources of Cedar Valley. The UGS is preparing a comprehensive report of the findings of this study, which we anticipate will be made available to the public later this year. The ground-water flow model code will be made available to government agencies and consulting scientists as a planning tool.

## ABOUT THE AUTHORS

**J. Lucy Jordan** is a hydrogeologist in the UGS Ground Water and Paleontology Program. She has a B.S. degree in Geology from North Dakota State University and an M.S. degree in Geology from the University of Montana. Lucy worked on mining-related ground-water contamination as a consultant to Kennecott Utah Copper and on water-supply and protection projects for other consulting firms in Utah for a decade prior to joining the UGS in 2004. Lucy's work with the UGS has focused on water-resource assessments in Utah, including water-quality studies, aquifer testing, and computer-based modeling projects. She is currently managing the surface-water monitoring program in Snake Valley in western Utah.

**Walid Sabbah** is a hydrogeologist/ground-water modeler in the UGS Ground Water and Paleontology Program. Walid has a B.S. degree in Geology from Yarmouk University and an M.S. degree in Hydrogeology from the University of Jordan. He worked for eight years as a hydrogeologist before returning to school to pursue a doctorate, and in 2004 received his Ph.D. in Civil and Environmental Engineering with emphasis in GIS and hydrological modeling from Brigham Young University. He also worked as an adjunct Assistant Professor at Utah Valley University for a year and a half prior to joining the UGS in 2006.

# THE FOSSIL PREPARATION LAB AT THE UTAH GEOLOGICAL SURVEY

## BRINGING EARTH'S ANCIENT PAST TO LIFE

*by Scott Madsen*

The science of paleontology is the study of ancient life. By studying extinct organisms, paleontologists can attempt to reconstruct past ecosystems and understand how animals and plants adapted to the environments in which they lived. Evidence of this ancient world comes from the fossilized remains of life that have been quarried from rocks or excavated from sediment. But before we can fully appreciate or understand these long-extinct organisms, the fossils must first undergo a long and painstaking process of laboratory preparation.

The vast backcountry and badlands of Utah are an especially good place for field paleontologists to make new discoveries. Much of the paleontological research at the Utah Geological Survey (UGS) focuses on the dinosaurs and other life of the Mesozoic Era (about 250 to 65 million years ago). UGS paleontologists, colleagues, and volunteers spend summers finding and excavating dinosaur bones and then encasing them, rock and all, in protective plaster and burlap "jackets" for transport to the preparation lab at the UGS's Utah Core Research Center. But this is only the beginning of getting the bones ready for study and exhibit. The process of removing the rock from the bones and stabilizing them is known as "preparation," and the people who specialize in this craft are called "preparators."

Although most of the fossil bones you see on display in museums might look strong, most of them were not found in that condition. A typical fossil is riddled with cracks, pieces might have eroded away before it was collected, or it may be porous as a sponge. Some bones are as thin as paper and others might be as small as pinheads. A preparator needs to learn how to deal with all of these problems so that bones can be safely studied, stored, and displayed.

*Volunteer preparator Judy Sanders cleans an iguanodont shoulder bone (scapula) that rests in a plaster jacket.*

*UGS fossil preparator Don DeBlieux removes iguanodont bones from a plaster field jacket.*

Fossil preparation has changed a lot since the old days of the hammer and chisel. On a typical day, the "prep lab" at the UGS will be filled with the buzz of airscribes (small handheld pneumatic jackhammers). These tools gently pulverize the rock around the fossil and allow the preparator to expose the bone a little at a time. The preparators at the UGS also use miniature sandblasters to remove rock. As cracks in bone are encountered, they can be filled with glue, or the bone fragments can be pulled apart, cleaned piece by piece, and glued back together again. Shellac is also a thing of the past. Modern prep labs use special plastic materials dissolved in solvents to reattach and consolidate spongy and shattered bones. Dental tools are still handy for scraping off small bits of rock, although these have mostly been replaced by needles made of carbide and other strong metal alloys.

UGS fossil preparators Don DeBlieux and Scott Madsen, and a small team of dedicated volunteers are currently busy preparing several dinosaurs from Early Cretaceous-age (145 to 100 million years ago) rocks of Utah. These include the skeletons of new species of plant-eating dinosaurs (iguanodonts) and new species of small carnivorous bird-like dinosaurs (similar to the famed sickle-clawed *Utahraptor*), all from quarries near Green River, Utah. Many of these bones are so small and delicate they must be prepared under a microscope using carbide needles.

When new plaster field jackets are opened in the lab, surprises are common. One jacket, known from field observation to contain part of an iguanodont tail, was also hiding three skulls, including those of a juvenile iguanodont and a crocodile; when turned over, the same block of rock revealed yet another tail, that of a small carnivorous dinosaur. A less welcome surprise was a scorpion that had somehow managed to survive being entombed in a plaster jacket for 15 months! It was later returned to the wild.

Fossil preparation is slow, painstaking work. All of these projects will take years of labor to complete, but when finished will reveal new and interesting chapters in the story of life on Earth. ■

*UGS fossil preparator Scott Madsen uses a microscope and carbide needle to prepare fragile iguanodont bones.*

*UGS preparator Don DeBlieux next to a partially excavated dinosaur humerus (upper arm bone) in the field.*

*The same bone after preparation by volunteer Tom Mellenthin at the UGS prep lab. Sections of bone were glued together with epoxy resin; the blue strap and padding help hold the bone together while the epoxy sets.*

# UTAH GEOLOGICAL SURVEY'S WEST DESERT GROUND-WATER MONITORING NETWORK

## Progress Report

*by Hugh A. Hurlow*

The Utah Geological Survey's west desert ground-water monitoring network is essentially in place and fully operational. Requested by the Utah State Legislature in 2007, the network was established in response to water-development projects in east-central Nevada and west-central Utah. The network includes wells in Snake and Tule Valleys and Fish Springs Flat, and surface-flow gages in Snake Valley.

The monitoring wells include 68 individual PVC wells in 51 boreholes (one to three wells per borehole) at 27 sites (one to three boreholes per site). Sixty of these wells are equipped with pressure transducers that measure water levels hourly. Eleven surface-flow gages are in place at six springs, and the data are streamed continuously to the Utah Division of Water Rights Web site (www.waterrights.utah.gov/distinfo/realtime_info.asp). We are currently constructing a database that links to the project Web site to manage the transducer data. The UGS maintains the project Web site (geology.utah.gov/esp/snake_valley_project/index.htm), which includes all currently available water-level and drilling data from the network, a Google Earth-compatible location file that describes the project sites and includes data links, and photographs from the project.

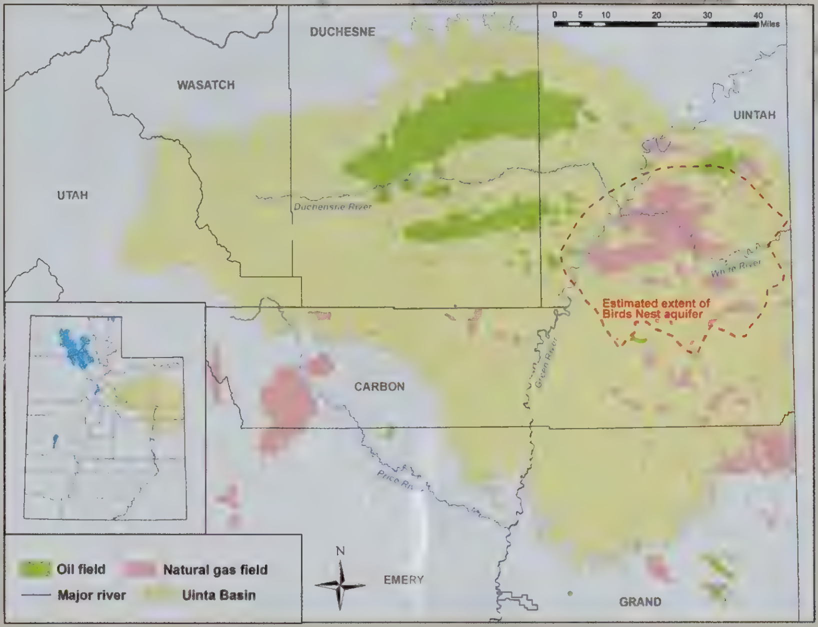
Work on the project from May through December 2009 focused on sampling ground water from wells, installing surface-flow gages, maintaining the transducer network, and installing shallow piezometers at wetlands in spring-outflow areas. Well sampling occurred in two main phases. The UGS, U.S. Geological Survey's Utah Water Science Center, and Southern Nevada Water Authority collaborated to collect general-chemistry, stable- and radiogenic-isotope, and dissolved-gas samples from 14 wells in the network during May. Hurlow sampled 17 additional wells during June through September. Lucy Jordan (UGS) and Aaron Hunt (Division of Water Rights) completed installation of the stream gages and radio telemetry system in December, after much hard work from March through December. Fish Springs Wildlife Refuge and the Baker family kindly donated significant labor to assist flume installation at several sites. UGS geologists Stefan Kirby and Matt Affolter continued to download transducer data quarterly and improve the transducer network. In a related effort, the U.S. Environmental Protection Agency funded UGS geologist Richard Emerson to assist with installation of 60 shallow piezometers in five spring-outflow areas as part of a project to establish baseline physical habitat conditions of wetlands in Snake Valley.

Remaining work for the project includes analysis of aquifer-test data, analysis of water-chemistry data, completing the wetlands piezometer network, developing a water-level database that links directly to the Web page, and writing the report.

# SALINE WATER DISPOSAL IN THE UINTA BASIN, UTAH

## PROTECTING FRESH WATER WHILE ALLOWING FOR INCREASED HYDROCARBON PRODUCTION

*by Michael D. Vanden Berg*



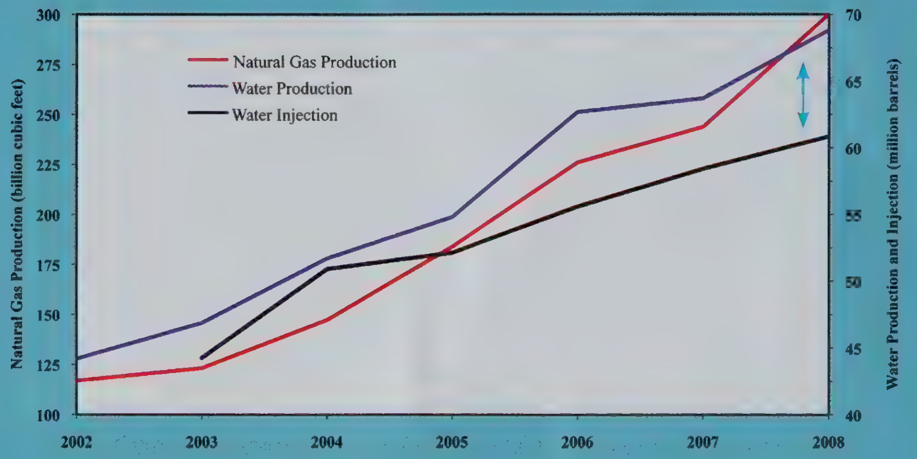
*The Birds Nest aquifer in the eastern Uinta Basin is a promising reservoir for the disposal of saline water that accompanies hydrocarbon production.*

Saline water disposal is one of the most pressing issues with regard to increasing crude oil and natural gas production in the Uinta Basin of northeastern Utah. Conventional oil fields in the basin provide 67 percent of Utah's total crude oil production and 70 percent of Utah's total natural gas, the latter of which has increased 60 percent in the past 10 years. Along with hydrocarbons, wells in the Uinta Basin produce significant amounts of salty water—nearly 4 million barrels of saline water per month in Uintah County and nearly 2 million barrels per month in Duchesne County. As hydrocarbon production increases, so does saline water production, creating an increased need for economic and environmentally responsible disposal plans. Current water disposal wells—wells specifically used to re-inject saline water underground—are near capacity, and permitting for new wells is being delayed because of a lack of technical data regarding potential disposal aquifers and questions concerning contamination of freshwater sources. Many companies are reluctantly resorting to evaporation ponds as a short-term solution, but these ponds have limited capacity, are prone to leakage, and pose potential risks to birds and other wildlife. Many Uinta Basin operators claim that oil and natural gas production cannot

*A) Birds Nest aquifer in outcrop along Evacuation Creek, eastern Uinta Basin. The large cavities resulted from the dissolution of saline minerals, creating the aquifer's porosity (percent of pore space) and permeability (a measure of how effectively the pores are connected). B) Dissolution of saline minerals in core from central Uintah County (yellow bars equal 1 inch).*

reach its full potential until a suitable, long-term saline water disposal solution is determined.

The Utah Geological Survey (UGS) is currently half-way through a three-year, joint UGS–U.S. Department of Energy-funded study investigating the aquifers in the Uinta Basin to help facilitate the development of prudent saline water disposal plans. The project is divided into three parts: (1) re-mapping the base of the moderately saline aquifer in the Uinta Basin, (2) creating a detailed geologic characterization of the Birds Nest aquifer, a potential reservoir for large-scale saline water disposal, and (3) collecting and analyzing water samples from the eastern Uinta Basin to establish baseline water quality.



*Natural gas production, water production, and water injection in the Uinta Basin, Utah, 2002–2008. The gap between water production and water injection (indicated by blue arrow) has widened as natural gas production has increased, leading to a need for the development of mitigation strategies.*

*Birds Nest aquifer outcrop along the White River, eastern Uinta Basin, Utah.*

**Part 1:** Regulators currently stipulate that saline water must be disposed of into aquifers that already contain moderately saline water (water that averages at least 10,000 parts per million total dissolved solids). These underground zones are currently determined using 25-year-old data complied on a less-than-useful paper map. The UGS plans to re-map this moderately saline water boundary in the subsurface using a combination of actual water chemistry data collected from various sources and by analyzing geophysical well logs. By re-mapping the base of the moderately saline aquifer using more robust data and more sophisticated computer-based mapping techniques, regulators will have the information needed to more expeditiously grant water disposal permits while still protecting freshwater resources.

**Part 2:** Eastern Uinta Basin gas producers have identified the Birds Nest aquifer, located in the Parachute Creek Member of the Green River Formation, as the most promising reservoir suitable for large-volume saline water disposal. This aquifer, ranging in thickness from less than 100 feet on the basin margins to greater than 300 feet in the basin's center, formed from the dissolution of saline minerals which left behind large open cavities and fractured rock. Understanding the aquifer's areal extent, thickness, water chemistry, and zones of differential dissolution will help determine possible saline water disposal volumes and safe disposal practices, both of which could directly impact the success of increased hydrocarbon production in the region.

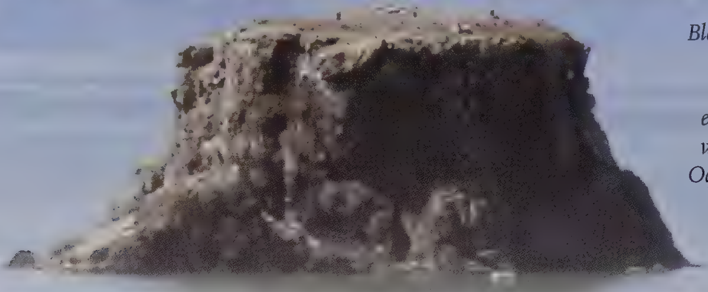
**Part 3:** The UGS has determined a regulatory need for baseline water quality and quantity data for lands identified in the eastern Uinta Basin as having oil shale development potential. Water-quality degradation could result from new oil shale developments via mining and surface retort or in-place processes. The UGS has identified 17 sites in the area, including wells, springs, and streams, that will be sampled and analyzed on a bi-annual basis. This information will provide a baseline water quality profile, which can be used to compare with future data after petroleum development begins.

This multifaceted study will provide a better understanding of the aquifers in the Uinta Basin, giving regulators the tools needed to protect precious freshwater resources while still allowing for increased hydrocarbon production. To find out more about this study or to download quarterly reports and recent presentations, visit the UGS Web site: geology.utah.gov/emp/UBwater_study. ■

# GLAD YOU ASKED

## HOW MANY ISLANDS ARE IN GREAT SALT LAKE?

*by Jim Davis*



*Black Rock, a steep-sided offshore rock island (or "sea stack") near Saltair, was the site of Utah's first recorded community beach excursion in 1851. Sea stacks are created by wave erosion of a headland, in this case the Oquirrh Mountains, which eventually leaves behind isolated rock islands.*

Great Salt Lake has islands from small to large, from one corner of the lake to the other. But how many islands are there? The question is not as straightforward as one might think. Although there are 17 officially named islands, answers to the question typically range from zero to 15.

**It All Depends. . .**

Great Salt Lake is in a closed basin, an area without any drainage outlet. The elevation of the lake's surface changes continually, reflecting changes in weather and climate; heavy precipitation and low evaporation rates cause the lake level to rise, whereas drought and heat will result in a declining lake level. The lake level can change 2-plus feet a year, and because the basin floor slopes very gently, the shoreline advance or retreat can be a mile or more in certain areas.

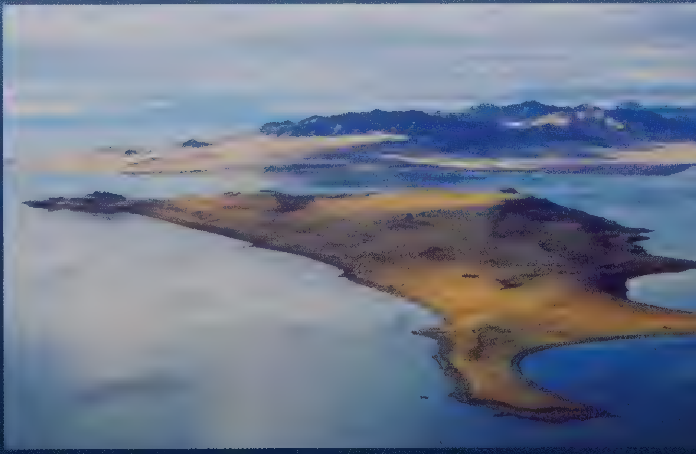
Great Salt Lake's ups and downs have exceeded a 20-foot range in historical times. At high lake levels some islands submerge and new ones are created by the water enclosing higher topography. At low lake levels new islands emerge and some adjacent islands merge with each other or with the mainland. All islands become connected to the mainland during very low lake levels (e.g., 1963), and the maximum number of islands occurs during very high lake levels (e.g., 1873, 1986–87). A few examples illustrate how the number of islands changes with changing lake levels. Badger Island is submerged at historic high levels (4212 feet above sea level), and Goose Island in Farmington Bay is submerged at the average historical lake level of 4200 feet. Strongs Knob and Stansbury Island, technically peninsulas, are tied to the mainland by dry land until the lake level is a few feet higher than average. Some islands divide into multiple islands at higher lake levels. Strongs Knob spawns an islet or two at higher levels, as does Cub Island, splitting into two smaller islets—Greater Cub and Lesser Cub. Antelope Island is a peninsula at lake levels below average. Egg Island and White Rock were connected to Antelope Island during the lowest historical lake level (4191.35 feet). Carrington, Badger, Hat, and Stansbury Islands all combine during low lake levels by way of sand bars.

So, discrepancies in the reported number of islands are to be expected, depending on the level of the lake at the time of counting. The 11 most commonly cited islands are Antelope, Badger, Carrington, Cub, Dolphin, Egg, Fremont, Gunnison, Hat, Stansbury, and Strongs Knob. Islands often left out of the count are Black Rock and White Rock, Browns and Goose in Farmington Bay, and the Bear River Bay islands of Rock and Goose (the other Goose Island). All 17 islands have official names recognized by the U.S. Board on Geographic Names (geonames.usgs.gov/).

**Why So Many Islands?**

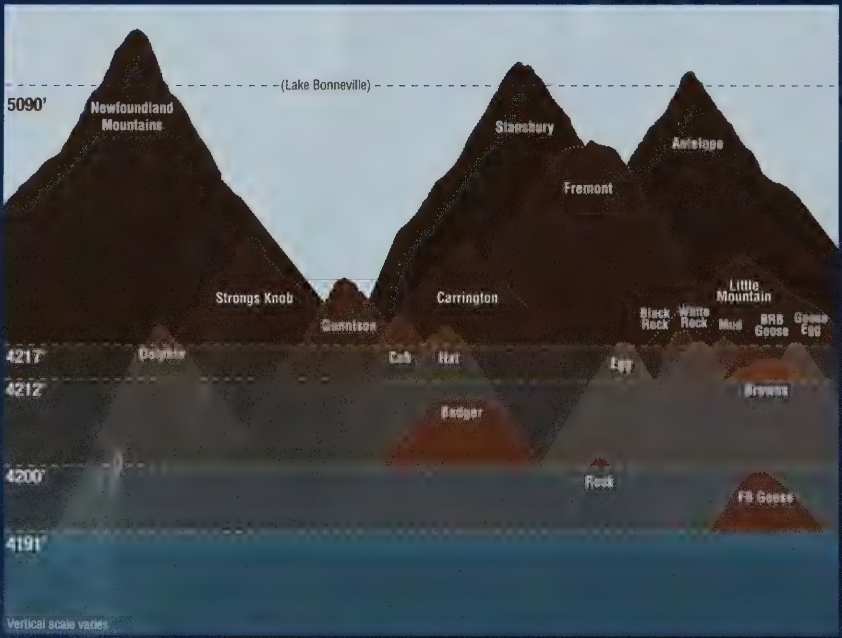
The major islands, such as Antelope, Stansbury, and Fremont Islands, as well as some of the minor islands, are actually moun-

*Wide sandy beaches span scalloped coves of the Gunnison Island shoreline, a State Wildlife Management Area closed to the public.*



*Aerial view (looking north) of Fremont Island and the nearby Promontory Mountains. Fremont Island has also been called Disappointment Island, Castle Island, and Miller's Island. (Photo source: Don Currey, University of Utah.)*

*Islands of Great Salt Lake.*



*Great Salt Lake island family portrait: The number of islands varies depending on lake level. The four elevations of the surface of Great Salt Lake (up to 4217 feet) represent, from bottom to top, the historical lowstand, historical average, historical highstand, and late-prehistoric (ca. 1700) highstand levels. Also shown is the highstand level of Lake Bonneville, Great Salt Lake's Ice Age predecessor. BRB, Bear River Bay; FB, Farmington Bay.*

tain ranges that poke up above the lake. Great Salt Lake lies within the eastern part of the Basin and Range Province; because of the characteristic topography of this physiographic province—north-south-trending isolated mountain ranges and adjacent valleys—Great Salt Lake hosts an unusually large number of islands.

In contrast, the low-lying islands of Great Salt Lake's eastern edge were constructed by the Bear, Jordan, and Weber Rivers. As the river channels migrate, erosion and deposition of sediment creates local high points. Additionally, liquefaction from large-magnitude earthquakes roils this soggy landscape, forming bumpy topography. Some of these low-lying islands are termed "knolls" rather than islands—for instance Rabbit, Cow Bay, and Round Knolls in Farmington Bay, and The Knoll by Bear River.

An artificial but nonetheless remarkable island is Goose Egg in the Farmington Bay Waterfowl Management Area (not to be confused with the other two Goose Islands). Goose Egg is an island created from material generated in the May 1983 Rudd Canyon debris flow in northern Farmington in Davis County, which was hauled to and piled up in Farmington Bay. Another island of note is Mud Island, about 5 miles northeast of Fremont Island in Ogden Bay. For nearly a century it could be found labeled on maps, but no longer. Mud Island still makes an appearance between particular lake levels. In 1850, Captain Howard Stansbury and his exploration crew set up a station on Mud Island. He described it as a point of rocks surrounded by a mud plain . . .

> *". . . a belt of soft, black mud, more than knee-deep lay between the water and hard rocky beach, and seemed to be impregnated with all the villainous smells which nature's laboratory was capable of producing."*

### More Islands?

Two substantial islands add to the sum if we go back a few hundred years to a period of cool climate known as the Little Ice Age. The Newfoundland Mountains became an island some decades before the year 1700 when the lake rose to approximately 4217 feet, spilling out into the west desert and Bonneville Salt Flats, expanding its surface area by 900 square miles and encompassing "Newfoundland Island." The State of Utah would recreate this situation in 1987, when the lake's water was pumped into the west desert to control flooding associated with the lake's historical highstand. Also, Little Mountain in Weber County was an island for awhile in the 17th century. This is the place where famed American explorer John C. Frémont summited for his first panoramic view of Great Salt Lake in 1843. ■

# GEOSIGHTS

## FREMONT INDIAN STATE PARK

### SEVIER COUNTY, UTAH

*by William F. Case*

*Fremont Indian petroglyphs pecked into the Joe Lott Tuff. The dark surface was produced by weathering of the lighter colored tuff. (Photo courtesy of Fremont Indian State Park).*

Fremont Indian State Park is named after a diverse group of people, the Fremont Indians, who lived in Utah from A.D. 400 to 1350. The park exists because of successful archaeological excavations in Clear Creek Canyon prior to construction of Interstate 70 between Richfield and Cove Fort, Utah. There are at least 10 Fremont sites within the park.

In 1983 local elementary school students told Brigham Young University archaeologists that there were pottery shards and collapsed dwelling depressions on top of Five Finger Ridge. At the time bulldozers were removing the surficial deposits of Five Finger Ridge for use as highway fill. The archaeologists quickly recovered hundreds of artifacts from Five Finger Ridge; these and other Fremont artifacts are housed and displayed in the Fremont Indian State Park museum that opened in 1987.

Clear Creek Canyon has afforded a human connection between the Colorado Plateau and Basin and Range areas since at least 12,000 B.C. The area has provided habitat or layover essentials for Paleoindians, Fremont Indians, more recent Native Americans, and Mormon pioneers. Interstate 70 is the latest human connection between Richfield and Cove Fort.

How has the geology of Clear Creek Canyon contributed to the attraction of so many people over such a length of time? Clear Creek flows east to the Sevier River through the Clear Creek downwarp, a geological structure that began forming 27 million years ago. This downwarp helped form the passage between the formidable Pahvant Range to the north and Tushar Mountains to the south.

*Fremont Indian State Park Museum. Low distant clouds lie over the Mount Belknap caldera. The Sevier River Formation forms the light-colored hills in the middle distance. Photo courtesy of Vandy Moore (Fremont Indian State Park).*

*An airfall volcanic ash layer is exposed in this outcrop of the pink unit of the Joe Lott Tuff along State Route 4 near I-70 exit 17.*

The oldest rock unit at the park is the 19-million-year-old Joe Lott Tuff, named after an early Mormon pioneer who settled in Clear Creek Canyon. The rock is a welded volcanic-ash avalanche deposit containing scattered pieces of rhyolite lava (ash-flow tuff) that was produced by an explosive volcanic eruption. The massive eruption created the Mount Belknap caldera located about 10 miles south of Clear Creek Canyon. The tuff is exposed in the high cliffs in the canyon. The surface of the originally white, pink, and gray tuff has weathered to darker colors and serves as a "blackboard" for Fremont Indian rock art.

Overlying the Joe Lott Tuff, the Sevier River Formation consists of sandstones, siltstones, conglomerates, volcanic ashes, and lava flows that were deposited in lake basins, rivers, and alluvial fans between about 5 and 14 million years ago, when the present topography of the Basin and Range area began forming. The Sevier River Formation was uplifted and tilted around 5 million years ago. Where the Sevier River Formation is not capped by conglomerate, its sandstones and siltstones are easily eroded, and the resulting sediment has provided valley fill suitable for construction materials for buildings and for growing crops. Excellent exposures of the Sevier River Formation can be seen at the nearby Castle Rock Campground south of I-70 (see "GeoSights" article in the September 2006 issue of *Survey Notes*).

Several years ago, local-area residents and amateur naturalists Jeff and Denise Roberts found fossils of two previously unknown species of tiny rodents related to modern deer and pocket mice in the Sevier River Formation near the mouth of Clear Creek Canyon. In addition to identifying new species, the finds are significant because mammal fossils dating to the time of the Sevier River Formation are exceedingly rare in Utah.

Clear Creek tributary drainages, particularly Dry Creek and First Spring Hollow, provide sand and silt eroded from the Sevier River Formation and landslides in the Joe Lott Tuff for alluvial fans that extend into the canyon. The fan surfaces are good agricultural locations, and the tributary stream flow supplements the water supply in the canyon. ■

*Tilted strata of the Sevier River Formation capped by resistant conglomerate near the mouth of Clear Creek Canyon.*

**How to get there:** Fremont Indian State Park is on the north side of I-70. From the I-15/I-70 interchange south of Cove Fort in Millard County, head east on I-70 to exit 17. Exit 17 is about 20 miles southwest of Richfield in Sevier County. Follow the signs to Fremont Indian State Park. For more information, visit stateparks.utah.gov/parks/fremont.

# SURVEY NEWS

## EMPLOYEE NEWS

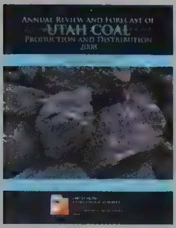
The Energy and Minerals Program welcomes **Andrew Rupke** as the new industrial minerals geologist. Andrew has an M.S. in Geology from the University of Utah and has worked for Graymont Lime for the past five years.

**Toby Hooker** recently joined the Ground Water and Paleontology Program as a wetlands specialist and will be working on EPA-supported projects at Snake Valley and near the Bear River Bay. Toby has a Ph.D. in Soil Microbiology and Biogeochemistry from Utah State University.

**Jim Levy** has joined the ever-growing Utah State Energy Program (USEP). He will be working as a project specialist under the American Recovery and Reinvestment Act programs. Jim comes to the USEP with over 20 years experience in the building lighting industry. Most of his career has been in California working for international firms, and most recently he was Vice President of Up-Light Electric Engineering, Inc. Jim is the first DNR employee to own a 100 percent electric car. **Megan Golden** left the USEP in March to pursue other interests.

# SURVEY NEWS

## NEW PUBLICATIONS

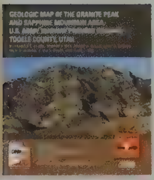


Annual review and forecast of Utah coal production and distribution—2008, prepared by Michael D. Vanden Berg, 37 p., ISBN 978-1-55791-824-7, **C-110** .......................... **$12.95**

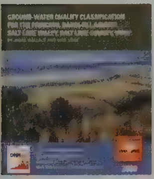
Geologic map of the St. George and east part of the Clover Mountains 30' x 60' quadrangles, Washington and Iron Counties, Utah, by Robert F. Biek, Peter D. Rowley, Janice M. Hayden, David B. Hacker, Grant C. Willis, Lehi F. Hintze, R. Ernest Anderson, and Kent D. Brown, 108 p., 2 pl., scale 1:100,000, ISBN 1-55791-816-3, **M-242** ................ **$19.95**

Glacial geologic map of the Uinta Mountains area, Utah and Wyoming, by Jeffrey S. Munroe and Benjamin J.C. Laabs, DVD (1 pl., scale 1:100,000 [contains GIS data]), ISBN 1-55791-825-2, **MP-09-4DM**..... **$24.95**

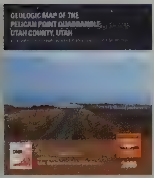
Utah's Energy Landscape, by Michael D. Vanden Berg, 41 p., ISBN 1-55791-823-6, **PI-95** ............................................. **$14.95**



Geologic map of the Granite Peak and Sapphire Mountain area, U.S. Army Dugway Proving Ground, Tooele County, Utah, by Donald L. Clark, Robert F. Biek, Grant C. Willis, Kent D. Brown, Paul A. Kuehne, J. Buck Ehler, and Carl L. Ege, CD (2 pl., scale 1:24,000), ISBN 1-55791-810-4, **M-238** ............................................ **$14.95**



Ground-water quality classification for the principal basin-fill aquifer, Salt Lake Valley, Salt Lake County, Utah, by Janae Wallace and Mike Lowe, CD (15 p. + 64 p. appendices, 3 pl.), **OFR-560** ........................................ **$19.95**



Geologic map of the Pelican Point quadrangle, Utah County, Utah, by Barry J. Solomon, Robert F. Biek, and Scott M. Ritter, CD (2 pl.), scale 1:24,000, ISBN 1-55791-820-1, **M-244** ............................................ **$14.95**

## 2009 UGS EMPLOYEE OF THE YEAR

Congratulations to **Mike Hylland** who was named the 2009 UGS Employee of the Year. Mike has worked for the UGS for 16 years and does an extraordinary job balancing duties as technical editor and geologic researcher. Mike is quite knowledgeable and professional, and his work ethic and demeanor are exemplary. As a patient, positive, and well-rounded reviewer, he strives for consistency and thoroughness, but is also flexible and willing to look at an author's particular viewpoint. His ongoing contributions to fault studies in northern Utah and maintenance of the Quaternary fault database are long-lasting. Overall, Mike's excellent technical skills and great temperament make him the perfect UGS role model.

## UTAH GEOLOGICAL SURVEY

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## UTAH'S ENERGY LANDSCAPE

Did you know that Utah is one of only six states that generate electricity from geothermal sources?

Did you know that Utah recently produced its one billionth ton of coal?

Did you know that Utah has the second lowest price for home-heating natural gas in the nation?

Did you know that Utah has been a net exporter of energy since 1980?

These little-known facts, along with many more interesting details, can be found in the Utah Geological Survey's new publication *Utah's Energy Landscape*—a visual-based comprehensive description of Utah's entire energy portfolio.

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H GEOLOGICAL SURVEY

# SURVEY NOTES

Volume 42, Number 3

September 2010

# Utah's Glacial Geology

# THE DIRECTOR'S PERSPECTIVE

by Richard G. Allis

This issue of *Survey Notes* highlights the outstanding examples of the effects of past glaciations preserved in Utah's geologic record. The last 2.5 million years on Earth are known to have been relatively cool and composed of glacial and interglacial periods. For the last 11,000 years we have been in an interglacial period, which has caused Utah's alpine glaciers to melt and Lake Bonneville to shrink to become the saline Great Salt Lake. The articles in this issue provide a backdrop to the current discussion about global warming. Clearly, large-scale climate change has occurred in Utah (and elsewhere) over all geologic timescales, so obvious questions arising from the current discussion are: What is the evidence for change in Utah over the last century, and if there is change, what is the cause?

The first question is easier to answer than the second one. The National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) maintains statistics on temperature trends at weather stations, and one product that has a long history in each state is the trends in "heating and cooling degree days." These trends are designed to provide up-to-date information on potential cooling fuel demands (from cooling degree days) and heating fuel demands (from heating degree days). Both trends are monitored by the energy utilities. A base temperature of 65°F is assumed, so temperatures above 65°F contribute to the cooling-degree compilation, and temperatures below 65°F contribute to the heating-degree compilation

The cooling-degree compilation, which is derived from the summer months, shows a pronounced warming trend since about 1970. However, the trend for heating degree days (mostly derived from the winter months) is less clear, with a possible warming trend from about 1970 to 2000, but a return to cooler winters since then. The two trends highlight the difficulties in trying to discern trends in a parameter like air temperature, which varies greatly on a daily and seasonal basis due to many factors. Fluctuations over a few years may not be representative of longer-term trends.

One set of data that naturally filters out the short-term air temperature fluctuations is the temperature observed at depth in boreholes. In northern Utah, the depth for potential freezing of the ground each winter extends to about 3 feet, and by about 30 feet depth, the temperature reflects the average annual temperature of about 50°F. Dr. David Chapman and his student Michael Davis, at the University of Utah Department of Geology and Geophysics, have been studying the longer-term air temperature changes inferred from boreholes extending to over 1000 feet depth. A recent compilation of data from boreholes around Utah shows a systematic trend of recent warming above about 300 feet depth (see figure). When this is modeled, the simplest, best-fit trend in air temperature is a steady warming of about 1.8°F since 1915. The boreholes are in fairly remote locations and should not have been subject to heat-island effects that sometimes have influenced air temperatures near major cities.

Another climate dataset with a long history for Utah is the snow pack. Has it shown any signs of shrinkage that might be attributable to warming over the last century? Randall Julander of the Natural Resources Conservation Service has studied Utah's snow pack trends and concludes that the data since the early 1930s are equivocal. If there has been a warming trend of 1–2°F, he suggests that it may not be enough to affect the snow pack, which is dominated by precipitation trends (for accumulation) and by short-wave radiation trends (for melting).

For the second question raised at the beginning of this article about the cause of this warming, the majority of climate scientists attribute the warming to human activities such as increased greenhouse gas emissions from fossil fuel combustion. Other possible natural drivers of global warming, which caused past glacial and interglacial periods, do not fit the observed trends. Where there is no agreement, however, is on the politics of whether and how to act on global warming. ■

*See figures on page 6.*

## CONTENTS

**Design:** *Richard Austin*
**Cover:** *View west down the glacially sculpted, U-shaped valley of Little Cottonwood Canyon, with Salt Lake Valley and the Oquirrh Mountains in the distance. Photo by Taylor Boden.*

*Survey Notes* is published three times yearly by Utah Geological Survey, 1594 W. North Temple, Suite 3110, Salt Lake City, Utah 84116; (801) 537-3300. The Utah Geological Survey provides timely scientific information about Utah's geologic environment, resources, and hazards. The UGS is a division of the Department of Natural Resources. Single copies of *Survey Notes* are distributed free of charge within the United States and reproduction is encouraged with recognition of source. Copies are available at *geology.utah.gov/surveynotes.* ISSN 1061-7930 ♻ Printed on recycled paper

# UTAH'S GLACIAL GEOLOGY

*by Bob Biek, Grant Willis, and Buck Ehler*

Note to reader: This issue of *Survey Notes* includes several articles that discuss geologic features related to glaciers; see the "Geosights" article on page 10 for definitions and illustrations of many of these features.

*View northwest from Dead Horse Pass in the Uinta Mountains (at the head of the West Fork of the Blacks Fork drainage basin); Deadhorse Lake is in the foreground. Note the smooth talus slopes on the left compared to the wrinkled surface formed by rock glaciers in the center of the photo. At the right side of the rock glacier complex, a rock avalanche deposit cuts across an older, subdued, grass-covered moraine and is itself partly covered by a younger moraine that formed about 1600 years ago. Recent work in this basin indicates that small glaciers were likely active at this location about 3500, 2500, and 1800 years ago, as well as during the Little Ice Age (150 to ~500 years ago). The large snowfield in the distance merges with a steep-fronted rock glacier; ongoing research will attempt to determine whether or not that rock glacier is active. Photo by Jeffrey Monroe.*

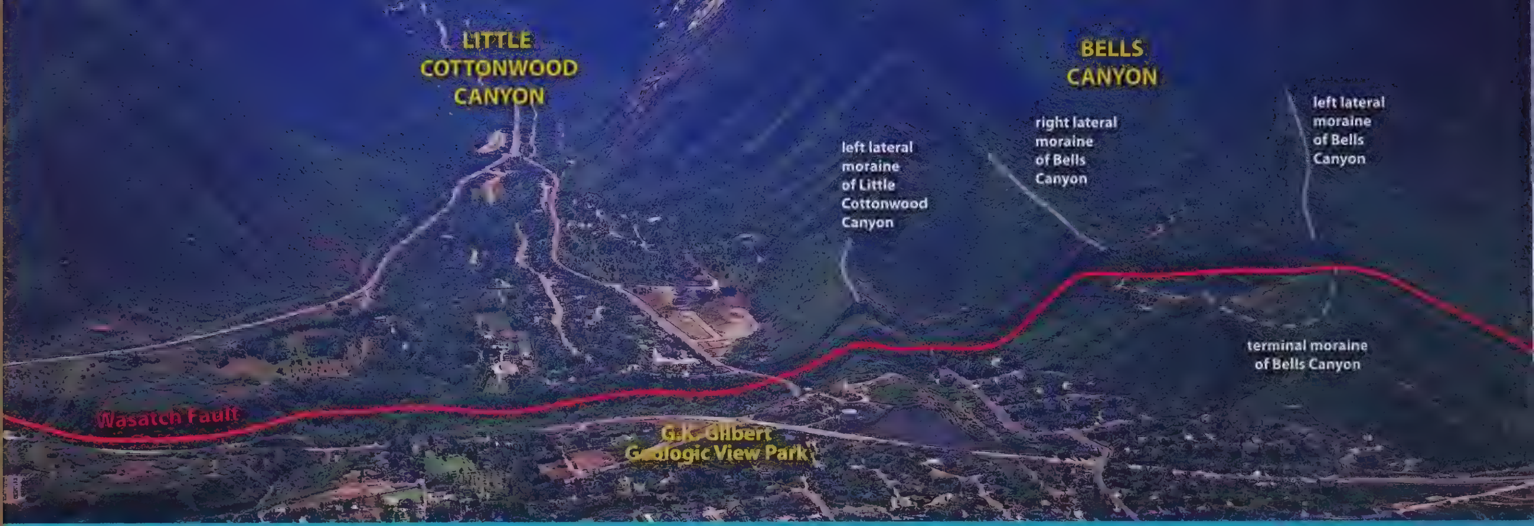
## Introduction

It is a humbling experience to drive up the Mirror Lake Highway, following the Provo River canyon deep into the heart of the western Uinta Mountains, and realize that, in the not-too-distant past, the canyon and alpine basins above were filled with hundreds of feet of glacial ice. Yet this canyon is just one of dozens in Utah's highest mountain ranges that held alpine glaciers during the Last Glacial Maximum (LGM), about 32,000 to 14,000 years ago. The glaciers also left behind stunning alpine scenery in the Wasatch Range, the high mountains and plateaus of central and southwest Utah, the La Sal Mountains, and even in some isolated mountains of the west desert.

The newly published *Glacial Geologic Map of the Unita Mountains Area, Utah and Wyoming* (UGS Miscellaneous Publication 09-4DM) by Jeffrey Munroe (Middlebury College) and Benjamin Laabs (SUNY – Geneseo) gives us an opportunity to reflect on the state's glacial history and what it reveals about past climate change. This map is the first comprehensive inventory of glacial deposits of the Uintas since Wallace W. Atwood published his seminal *Glaciation of the Uinta and Wasatch Mountains* a century ago in 1909. With renewed interest during the past decade spurred by development of new dating techniques, other researchers began investigating glacial deposits of the High Plateaus and Wasatch Range, collectively painting a portrait of the climate and landscape during the LGM.

Alpine glacial deposits are remarkably hard to date. And, because younger glacial advances typically scour away or cover deposits of older advances, the alpine glacial record is remarkably incomplete. Of the dozens of glacial advances that have occurred worldwide over the past 2 to 3 million years, only the last two are widely recognized in the Rocky Mountain region. Traditionally, researchers have used radiocarbon dating of plant debris associated with glacial deposits to determine the age of younger (less than about 60,000 years) glacial deposits. Recently, a new dating technique that uses cosmogenic exposure ages has proven useful (the technique measures the amount of time a glacier-deposited boulder has been exposed to the sun since last being moved), enabling more robust age control and correlation to other glacial deposits throughout the region.

Ironically, the best places to learn about glaciation are not in the spectacular glacier-carved U-shaped valleys themselves, but in nearby lake basins that preserve a more complete sedimentary record. In 1970, a 1000-foot-long sediment core was retrieved from Great Salt Lake. Known as the Burmester core (after the railroad causeway platform from which it was drilled), the core revealed evidence of



*Aerial view east to Little Cottonwood and Bells Canyons, which display prominent lateral and terminal moraines of the Last Glacial Maximum. These are the only two canyons in which glaciers extended all the way down to Lake Bonneville, a result of their favorably situated high-elevation upper basins and lake-enhanced snowfall. Photo courtesy of the late Kenneth Hamblin, Brigham Young University.*

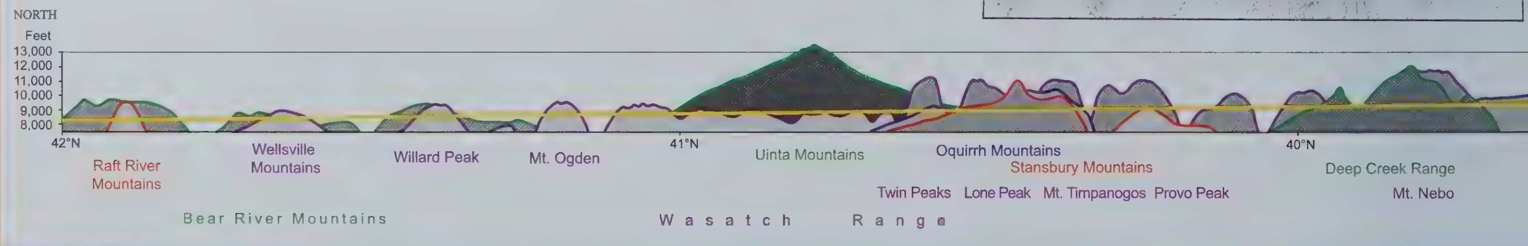
four large freshwater lakes that occupied the Bonneville basin in the past 780,000 years. Lake Bonneville was the last of these, occupying the basin from about 28,000 to 12,000 years ago; older lake deposits include those of the Little Valley Lake (150,000 years ago), Pokes Point Lake (420,000 years ago), and Lava Creek Lake (620,000 years ago). Lake Bonneville existed during the latest glaciation of nearby mountain ranges, and in fact had a profound effect on glacier development as described below. Similar glacial episodes likely correlated with the older lakes as well.

## Uinta Mountains

The spectacular Uinta Mountains, Utah's highest mountain range, held the state's largest alpine glaciers. Terminal moraines—arcuate ridges of unsorted rock and sediment that mark the farthest advance of a glacier—are among the most obvious glacial features. Heading up the characteristic U-shaped valleys, one may see recessional and lateral moraines, hanging valleys once occupied by smaller tributary glaciers, and amphitheater-like cirque basins studded with cirque and kettle lakes, striated and polished bedrock surfaces, glacial erratics, relict rock glaciers, and other glacial and neoglacial features. Downstream, valleys are choked with sediment deposited by glacial meltwater streams and rivers, which left behind terraced river channels and outwash plains now occupied by relatively small, "underfit" streams. Such features are dramatic evidence not only of the latest glaciation, but also reflect scouring by repeated glacial advances over the past 2 to 3 million years.

The north side of the range held numerous long valley glaciers (the longest was the Blacks Fork glacier at 22 miles long), whereas the south side was dominated by six larger but shorter glaciers. The larger southern glaciers resulted from bigger snow accumulation areas, a result of the gentle dip of bedrock strata in this area compared to steeper dips on the north side of the range. The gently dipping strata were more easily eroded laterally by glacial action, enabling the carving of broad, high-elevation cirque basins on the south side of the range—favorable areas for accumulation of large amounts of glacial ice.

One of the most remarkable features of Uinta Mountain glaciation is the profound effect that Lake Bonneville had on glacier development. As a result of lake-enhanced precipitation from Lake Bonneville, glaciers grew larger and extended to lower elevations in the western part of the Uintas, which was closer



*Utah map and north-south profile showing mountain and plateau crests high enough to have been glaciated during the Last Glacial Maximum (LGM). In northern Utah, glacial ice accumulated above elevations of about 8200 feet, whereas in southern Utah mountains needed to be above 10,000 feet to collect ice. Glaciologists use the term "equilibrium-line altitude" (ELA) to refer to the elevation above which snowfall will accumulate faster than it will melt (averaged over multiple years), thus thickening, compacting, and crystallizing into glacial ice. The position of an ELA is controlled by climate and thus varies over time, but when it is below mountain crests for long periods of time, glaciers develop. ELAs can also be used as a proxy to estimate temperature and precipitation during glacial advances. At the height of the LGM, central Utah was on average 7°F to 25°F (4–14°C) colder than today.*

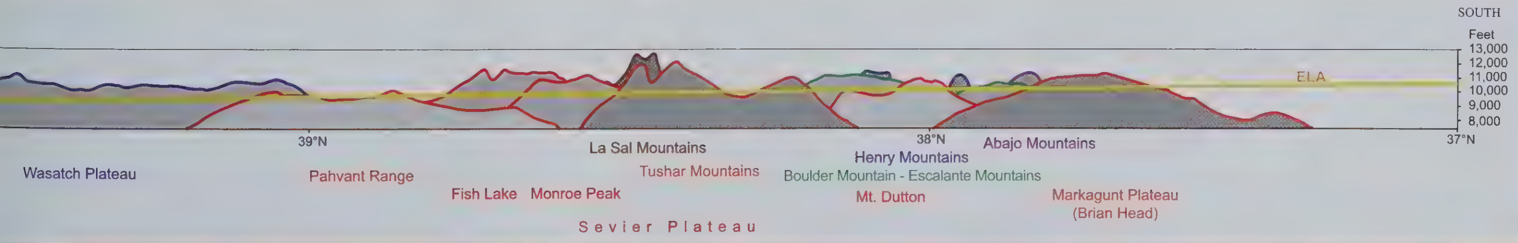
*The Uinta Mountains, showing the extent of glaciers at the height of the LGM, about 32,000 to 14,000 years ago (from Laabs and Munroe, 2009, UGS Miscellaneous Publication 09-4DM). Small cirque and valley glaciers occupied the western and eastern Uinta Mountains, whereas a broad ice field occupied the crest of the range, with all but the highest peaks and divides covered by ice. The largest valley glaciers were on the south side of the range. Glaciers at the west end of the range accumulated ice down to elevations of about 8500 feet, whereas those in the east only accumulated ice down to about 10,500 feet, a likely result of enhanced lake-effect precipitation due to nearby Lake Bonneville.*

to the lake (Great Salt Lake produces a significant though smaller version of "lake effect" precipitation today). Also, glaciers in the southwestern Uinta Mountains and nearby Wasatch Range retreated from their maximum extent by about 17,000 years ago, 2000 to 4000 years later than glaciers in other Utah mountain ranges. This was likely due to the enhanced precipitation, which allowed glaciers to survive longer through otherwise increasingly warmer and drier conditions at the end of the LGM.

Although the LGM peaked about 17,000 years ago in the Uinta Mountains, small cirque-floor moraines in the highest parts of many north-flank drainages provide evidence that small glaciers formed a few times since then. These moraines reflect small ice advances in latest Pleistocene to early Holocene time, and two drainages contain evidence of small glaciers in late Holocene time (last few thousand years). In many areas in the Rocky Mountains small glaciers also formed during the "Little Ice Age," which was just 150 to about 500 years ago, but few are recognized in the Uinta Mountains, possibly because of inadequate winter snowfall during this time. However, rock glaciers—surficial masses of ice-cored rubble that move downslope due to flowage of internal ice—are present above 10,000 feet; many of these may have been active during the Little Ice Age. Today, most appear to be dormant, but some exhibit evidence of active flow, including unvegetated, oversteepened fronts, ridges and troughs, ponds of silty meltwater, and springs near their toes.

## Wasatch Range

Parts of the Wasatch Range were also sculpted by glacial ice, nowhere more dramatically than at Little Cottonwood and Bells Canyons. Recently, Elliott Lips (Great Basin Earth Science, Inc.) and his colleagues studied new exposures near Little Cottonwood Canyon that revealed that ice advanced past the mouth of the canyon several times, including at least two minor advances before or during the highstand of Lake Bonneville about 18,000 years ago and at least one around 16,000 years ago, after the highstand. The moraine on the south side of the mouth of Little Cottonwood Canyon is much larger than the moraine on the north side because larger tributary glaciers entered the canyon from its south side (some formed classic hanging valleys visible in the canyon's lower reaches today). Conspicuous large granitic boulders on the north side of the canyon mouth record the height of glacial ice in this area. A much smaller ice advance in upper Little Cottonwood Canyon near Alta may have formed during a period of global cooling 12,800 to 11,500 years ago



called the Younger Dryas (at this same time, a nearly desiccated Lake Bonneville rose to about 60 feet above the average level of today's Great Salt Lake, forming the Gilbert shoreline).

Just south of Little Cottonwood Canyon, the much larger Bells Canyon moraine shows that its glacier remained stationary for a longer time, indicating that it was less influenced by events that caused the Little Cottonwood glacier to undergo several minor advances and retreats. In addition to providing clues about the last glaciation, the Bells and Little Cottonwood Canyon moraines provide other important geologic information. Both are cut by the Wasatch fault, and studies of the faulted deposits have revealed valuable information on the recurrence history of major earthquakes that shook Salt Lake Valley.

### Does Mount Timpanogos Have a Glacier Today?

Mount Timpanogos, the second-highest mountain in the Wasatch Range, dominates the eastern skyline of Utah Valley. During the late 1800s and early 1900s, the cirque basin below the peak of Mount Timpanogos held a permanent snowfield that has been called "Utah's glacier" or "Timp glacier"; since then, a small snowfield commonly remains in that area throughout the year. Whether or not glacial ice was ever present in recent historical time has not been rigorously documented, but is doubtful. The site now appears to be a relict rock glacier, but ice could still be present at its core.

### Other High Mountain Ranges and Plateaus of Utah

Most of Utah's highest mountain ranges and plateaus, those soaring over 8200 feet in elevation in northern Utah and over 10,000 feet in southern Utah, show evidence of glaciation. Isolated ranges in western Utah, including the Stansbury Mountains, Deep Creek Range, and Raft River Mountains, show evidence of significant alpine glaciers. Towering over the redrock desert near Moab, the La Sal, Henry, and Abajo Mountains also held glaciers during the LGM. Among the best studied glacial deposits outside of the Uinta Mountains and Wasatch Range are those in the High Plateaus of central and southern Utah. This region is the focus of recent work by Western State College of Colorado geologist David Marchetti, who combines geologic mapping and cosmogenic dating techniques to tease apart the history and past climates recorded by these deposits. The Wasatch, Sevier, Markagunt, and Aquarius Plateaus, and the Pahvant Range, Tushar Mountains, and Boulder Mountain all have documented evidence of glaciation during the LGM, and many show evidence of an earlier glaciation. Other slightly lower ranges may have had small glaciers.

The Crystal and Lowder Creek basins east of Brian Head on the Markagunt Plateau hold the southernmost glacial deposits in Utah. Recessional and lateral moraines and hummocky, stagnant ice topography are locally well developed, but sculpted bedrock is absent or inconspicuous, probably owing to the relatively small size and suspected short duration of the glaciers. Recent mapping by the UGS has revealed an older terminal moraine in front of these LGM deposits.

### Ancient Glaciers

Utah's mountains also contain ancient deposits associated with the world's most severe ice age, which occurred during the Precambrian Cryogenian Period, a time commonly referred to as snowball earth. Glacial deposits from this time are present in bedrock in Big and Little Cottonwood Canyons, on Antelope and Fremont Islands, and in several other western Utah mountain ranges. In the Wasatch Range, these 700- to 750-million-year-old deposits are known as the Mineral Fork Formation, poorly sorted and now-lithified sediment deposited from a retreating Greenland-like continental ice sheet that cut across underlying coastal-plain, estuarine, and tidal-flat sediments of the Big Cottonwood Formation.

### Summary

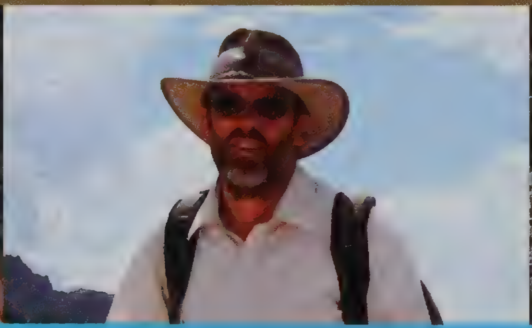
The stunning alpine scenery of Utah's highest mountains is the cumulative effect of repeated alpine glaciations over the past 2 to 3 million years that is linked to a worldwide pattern of glacial and interglacial cycles. Because successive glaciers typically overrode or buried older glacial deposits and landforms, only those of the last two glacial episodes are well documented in the state. Utah was largely ice-free by about 14,000 years ago, but younger glacial deposits from small ice advances associated with more recent minor climate fluctuations are known in the Uinta Mountains and High Plateaus of southwest Utah, and suspected in other areas. No glaciers are present in Utah today, but rock glaciers are known in many ranges; most are doubtless dormant, but some may still be active, including several in the Uinta Mountains. ■

## ABOUT THE AUTHORS

**Bob Biek** is a Senior Scientist with the UGS's Geologic Mapping Program. Since joining the Survey in 1996, he has published over two dozen geologic maps of 7.5' quadrangles along Utah's Wasatch Front and in the Heber Valley area, as well as in southwestern Utah. He was the lead author on the recently published St. George 30' x 60' quadrangle geologic map, and is currently in the middle of a four-year effort to compile a geologic map of the Panguitch 30' x 60' quadrangle.

**Grant Willis** has been a mapping geologist with the UGS for 27 years, including 16 years as manager of the Geologic Mapping Program. He has authored or coauthored over 40 geologic maps, and is currently mapping Glen Canyon National Recreation Area.

**J. Buck Ehler** has been a Geographic Information Systems (GIS) Analyst/Cartographer with the UGS Geologic Mapping Program for five years. He is a proud Utah native who grew up in Emery County. Buck graduated from Utah State University with a bachelor's degree in Geography with minors in Geology and GIS.



Detail of late Pleistocene life in central Utah from a mural painted by Joe Venus at the College of Eastern Utah Prehistoric Museum.

# UTAH'S PLEISTOCENE FOSSILS:

## KEYS FOR ASSESSING CLIMATE AND ENVIRONMENTAL CHANGE

*by Don DeBlieux*

As highlighted in this issue of *Survey Notes*, Utah is an outstanding place to study the geology of the Pleistocene Epoch, the so called Ice Age. In addition to documenting the physical changes to the landscape, the geologic record also preserves evidence of Pleistocene plant and animal life. Many of Utah's Pleistocene species still live here today, but others no longer inhabit Utah or have disappeared completely. Investigation of Utah's Ice Age fossils provides important information on how plants and animals responded to past changes in climate. In this respect, it is not only fascinating to explore but is also pertinent to the issue of modern global climate change. By studying the effects of past climate change we can get a better idea of what changes we might expect in the future.

Dramatic climate fluctuations occurred throughout the Pleistocene. Glaciers advanced during colder and wetter times and retreated during warmer and drier times, and glacial lakes including Lake Bonneville expanded and contracted. These climate fluctuations changed the distributions of plants and animals as their preferred habitats were disrupted. Similarly, the distributions of plants and animals are changing today as cold-adapted species are forced to move farther north or to higher elevations, and species better suited to warm climates take their place. If climate change and habitat disruption occur slowly, then it is more likely that plants and animals can move to more favorable habitats. If environmental change proceeds quickly, then there may not be enough time for these movements and the result may be the local, and in some cases total, extinction of species.

Much of what we know about the large animals that inhabited Utah during the Ice Age comes from fossils unearthed from sediments that were deposited along the shores of Lake Bonneville. Gravel-quarrying operations along the Wasatch Front occasionally expose the bones of Pleistocene mammals such as the mammoth, musk ox, giant bison, ground sloth, and giant short-faced bear (see *Survey Notes*, v. 28, no. 3, May 1996). The fossils also include bones of animals such as horses and camels that went extinct in North America at the end of the Ice Age but survived in Asia.

One of Utah's most famous Pleistocene fossil discoveries was a Colombian mammoth skeleton excavated in 1988 from Huntington Canyon by former Utah State Paleontologist David Gillette. This fossil is exceptional because it is nearly complete, very well preserved, and found at a higher elevation than any other known mammoth. The skeleton is housed at the College of Eastern Utah Prehistoric Museum in Price. Casts of this specimen are on exhibit in a number of museums including the University of Utah Museum of Natural History (UMNH).

*Tobin Warner on the shore of Bear Lake with the mammoth vertebra he discovered.*

Over the past 10 years several significant Ice Age fossil finds have been reported to the UGS. Two musk ox horns were discovered in 2001 in Lake Bonneville sediments in a Tooele neighborhood by high school student Wendy Whitehead. She donated these specimens to the UMNH. A mammoth vertebra was discovered in 2004 on the shore of Bear Lake in northern Utah by Tobin Warner while he was attending a Boy Scout camp. Like Wendy, Tobin gave his fossil to the UMNH. To thank them for donating their finds to the museum where they are available for study, I made casts of the specimens so that they could have replicas for their personal collections. Casts of these specimens are also included in our Ice Age teaching kit (see

*Scientists Dave Madsen, Don Grayson, and Jeff Hunt examining Homestead Cave deposits for small animal fossils. Photo by Monson Shaver.*

"Teachers Corner" in this issue of *Survey Notes*). In 2004, we received a call from Earl and Elaine Gowin who informed us that a mammoth tusk was found during gravel quarrying on their ranch near Fillmore. We excavated the tusk and brought it back to our lab in Salt Lake City to be cleaned and stabilized. The Gowins also donated their fossil, and the tusk is now on public display at the Fillmore Library.

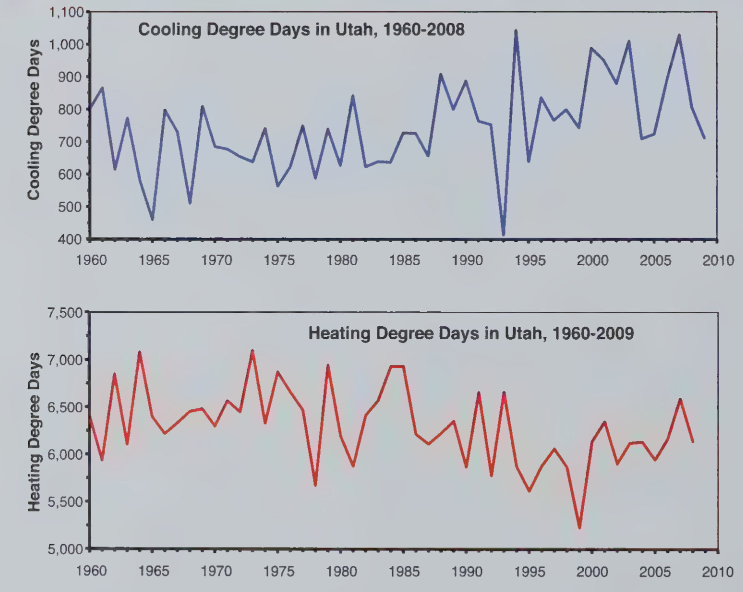
Large animals like the Columbian mammoth excite the imagination, but the small animals provide a great deal of information about climate and the environment because we know more about the habitat preferences of the small, still extant species. Most of what we know about Utah's smaller Ice Age animals comes from just a handful of sites. Several of these are caves located in Utah's west desert, such as Crystal Ball Cave in Millard County and Homestead Cave in Box Elder County. The bones of tens of thousands of animals, including small mammals, birds, and fish, have been recovered from these caves. Most of the bones are thought to have been brought to the caves by birds of prey and other carnivores. Packrat middens in the caves preserve a record of plants that grew in the area. Ongoing research on the materials from these caves is helping to paint a picture of ecosystem change in the context of changing climate and, because they were near Lake Bonneville, changing lake levels.

Scientists are also studying how living animals are responding to the challenges presented by a changing climate. One animal that is being studied in this regard is the pika. This small relative of the rabbit inhabits mountain talus slopes in much of the Rocky Mountains and some mountain ranges of the Great Basin. We know from the Pleistocene fossil record that pikas once inhabited valleys and lowlands in the Great Basin. Because pikas cannot withstand the high temperatures or eat the vegetation associated with today's valleys and lowlands, their populations are restricted to isolated mountain ranges. A number of pika populations have become locally extinct from mountain ranges in the Great Basin over the past several decades as a result of climate change and human impacts.

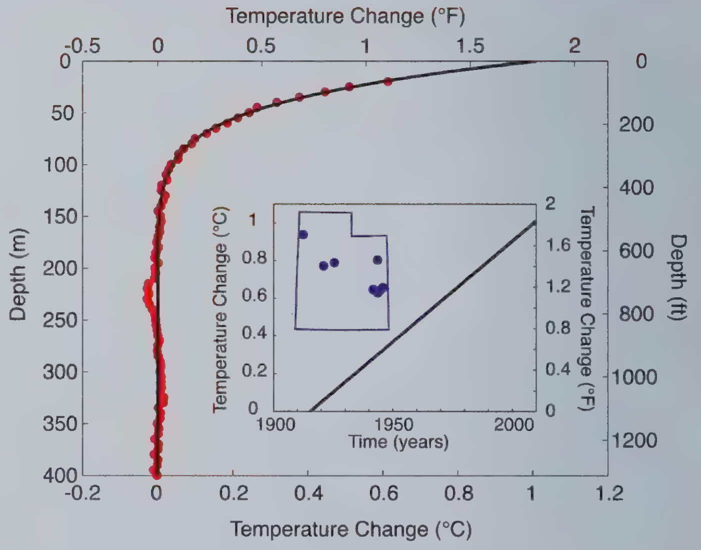
We know from the study of the past that our climate is highly variable and subject to dramatic shifts. We also know that these changes can take place relatively quickly, sometimes at a pace that is faster than the capacity of plants and animals to adapt. The study of Utah's Pleistocene geology and paleontology gives us information critical to assessing past environmental changes and can be used to evaluate the effects of future changes. ■

*A pika on alpine talus. Photo courtesy of Mike Hylland*

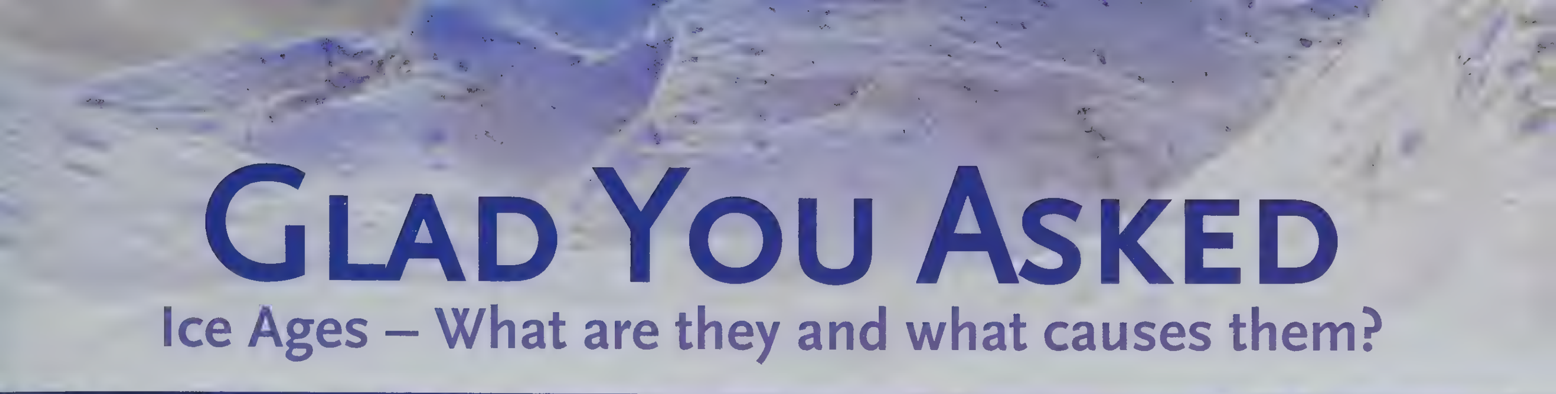
## THE DIRECTOR'S *continued* PERSPECTIVE



*Trends in cooling degree days (summertime) and heating degree days (wintertime) monitored by NCDC, and plotted on the UGS Web page: geology.utah.gov/emp/energydata/hcdegreedata.htm. This page contains links to the NOAA Web site.*



*Temperature change in Utah as determined from an average of borehole temperature measurements (red dots; map inset shows borehole locations). A linear ramp temperature fit to the observed data shows a surface warming of about 1°C (1.8°F) for Utah that began around the time of the first World War (inset) (Davis and Chapman, written communication).*



# GLAD YOU ASKED

## Ice Ages – What are they and what causes them?

*by Sandy Eldredge and Bob Biek*

**What is an ice age?**
An ice age is a long interval of time (millions to tens of millions of years) when global temperatures are relatively cold and large areas of the Earth are covered by continental ice sheets and alpine glaciers. Within an ice age are multiple shorter-term periods of warmer temperatures when glaciers retreat (called interglacials or interglacial cycles) and colder temperatures when glaciers advance (called glacials or glacial cycles).

At least five major ice ages have occurred throughout Earth's history: the earliest was over 2 billion years ago, and the most recent one began approximately 3 million years ago and continues today (yes, we live in an ice age!). Currently, we are in a warm interglacial that began about 11,000 years ago. The last period of glaciation, which is often informally called the "Ice Age," peaked about 20,000 years ago. At that time, the world was on average probably about 10°F (5°C) colder than today, and locally as much as 40°F (22°C) colder.

**What causes an ice age and glacial-interglacial cycles?**
Many factors contribute to climate variations, including changes in ocean and atmosphere circulation patterns, varying concentrations of atmospheric carbon dioxide, and even volcanic eruptions. The following discusses key factors in (1) initiating ice ages and (2) the timing of glacial-interglacial cycles.

One significant trigger in initiating ice ages is the changing positions of Earth's ever-moving continents, which affect ocean and atmospheric circulation patterns. When plate-tectonic movement causes continents to be arranged such that warm water flow from the equator to the poles is blocked or reduced, ice sheets may arise and set another ice age in motion. Today's ice age most likely began when the land bridge between North and South America (Isthmus of Panama) formed and ended the exchange of tropical water between the Atlantic and Pacific Oceans, significantly altering ocean currents.

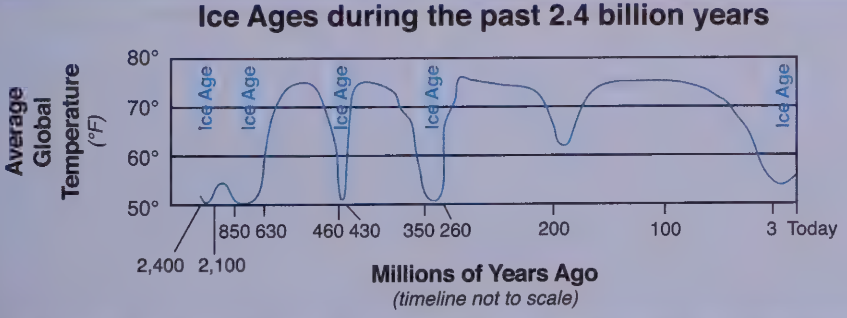
Glacials and interglacials occur in fairly regular repeated cycles. The timing is governed to a large degree by predictable cyclic changes in Earth's orbit, which affect the amount of sunlight reaching different parts of Earth's surface. The three orbital variations are: (1) changes in Earth's orbit around the Sun (*eccentricity*), (2) shifts in the tilt of Earth's axis (*obliquity*), and (3) the wobbling motion of Earth's axis (*precession*).

**How do we know about past ice ages?**
Scientists have reconstructed past ice ages by piecing together information derived from studying ice cores, deep sea sediments, fossils, and landforms.

Ice and sediment cores reveal an impressive detailed history of global climate. Cores are collected by driving long hollow tubes as much as 2 miles deep into glacial ice or ocean floor sediments. Ice cores provide annual and even seasonal climate records for up to hundreds of thousands of years, complementing the millions of years of climate records in ocean sediment cores.

Within just the past couple of decades, ice cores recovered from Earth's two existing ice sheets, Greenland and Antarctica, have revealed the most detailed climate records yet.

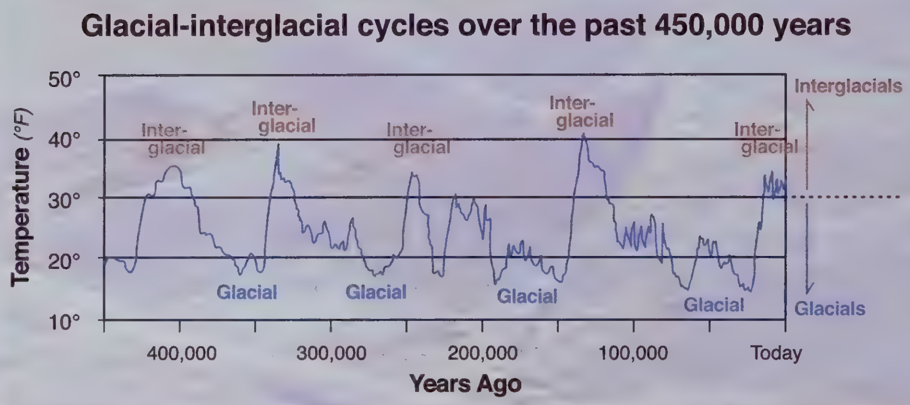
**Do ice ages come and go slowly or rapidly?**
Records show that ice ages typically develop slowly, whereas they end more abruptly. Glacials and interglacials within an ice age display this same trend.



Ice Ages during the past 2.4 billion years

*Simplified chart showing when the five major ice ages occurred in the past 2.4 billion years of Earth's history. Modified from several sources including* Dynamical Paleoclimatology: Generalized Theory of Global Climate Change, 2002, *by Barry Saltzman.*

On a shorter time scale, global temperatures fluctuate often and rapidly. Various records reveal numerous large, widespread, abrupt climate changes over the past 100,000 years. One of the more recent intriguing findings is the remarkable speed of these changes. Within the incredibly short time span (by geologic standards) of only a few decades or even a few years, global temperatures have fluctuated by as much as 15°F (8°C) or more. For example, as Earth was emerging out of the last glacial cycle, the warming trend was interrupted 12,800 years ago when temperatures dropped dramatically in only several decades. A mere 1,300 years later, temperatures locally spiked as much as 20°F (11°C) within just several years. Sudden changes like this occurred at least 24 times during the past 100,000 years. In a relative sense, we are in a time of unusually stable temperatures today—how long will it last?



*Four fairly regular glacial-interglacial cycles occurred during the past 450,000 years. The shorter interglacial cycles (10,000 to 30,000 years) were about as warm as present and alternated with much longer (70,000 to 90,000 years) glacial cycles substantially colder than present. Notice the longer time with jagged cooling events dropping into the colder glacials followed by the faster abrupt temperature swings to the warmer interglacials. This graph combines several ice-core records from Antarctica and is modified from several sources including* Evidence for Warmer Interglacials in East Antarctic Ice Cores, 2009, *L.C. Sime and others. Note the shorter time scale of 450,000 years compared to the previous figure, as well as the colder temperatures, which are latitude-specific (e.g., Antartica, Alaska, Greenland) temperature changes inferred from the Antarctic ice cores (and not global averages).*

**FOR MORE INFORMATION:**

*Abrupt climate change : inevitable surprises*, 2002, published by the National Academy of Sciences—a report from the Committee on Abrupt Climate Change, including members of the Ocean Studies Board, Polar Research Board, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, and National Research Council. Available online at **www.nap.edu/openbook.php?record_id=10136**

*North Greenland Eemian Ice Drilling project*— data from the 2010 NEEM project at **www.neem.ku.dk**

# SURVEY NEWS

## 2010 CRAWFORD AWARD

The Utah Geological Survey awarded its prestigious 2010 Crawford Award to UGS geologists **Bob Biek**, **Grant Willis**, **Janice Hayden**, and **Lance Weaver**, and UGS senior GIS analyst **Kent Brown** in recognition of their outstanding geologic map and interactive Web version of the *Geologic Map of the St. George and East Part of the Clover Mountains 30' x 60' Quadrangles, Washington and Iron Counties, Utah* (UGS Map 242).

This map is one of the most impressive the UGS has ever published. It has an incredible 228 different geologic units. The process of combining new mapping with older existing maps greatly improved the understanding of several geologic enigmas that have stood for decades. The team was particularly innovative at finding ways to present essential explanatory information in one supporting plate and a booklet, as well as the new interactive Web-based 3-D format. You can view the interactive 3-D version at geology.utah.gov/geo_guides/st_george/index.htm.

*2010 Crawford Award winners (left to right) Kent Brown, Lance Weaver, Bob Biek, Grant Willis, and Janice Hayden (inset).*

The Crawford Award was established in 1999 to commemorate the 50-year anniversary of the Utah Geological Survey. The award recognizes outstanding achievement, accomplishments, or contributions by a current UGS scientist to the understanding of some aspect of Utah geology or Earth science. The award is named in honor of Arthur L. Crawford, first director of the UGS.

# EMPLOYEE NEWS

**NEW EMPLOYEES:** **Gregg Beukelman** has joined the Geologic Hazards Program as a Project Geologist. Gregg received his M.S. in Geology from Boise State University, and has worked with the U.S. Geological Survey and as an engineering geologist in Idaho. **Stephanie Earls** has accepted the position as librarian for the Department of Natural Resources Library. She recently graduated with a Master of Library Science degree from the University of Washington, and also has a B.S. in Geology from the University of Utah.

The Utah State Energy Program (USEP) has three new employees: **Sherry Childers**, **Alair Emory**, and **Stefan Wilson**. Sherry has a B.S. in Behavioral Sciences from the University of Utah and many years of experience in project management in the engineering, oil and gas, and computer science industries. Alair has a B.S. in Chemistry and an M.S. in Mechanical Engineering from the University of Washington and over 20 years experience working on energy, biotech, and defense projects. Stefan has a B.S. in Economics from the University of Utah and has worked for several years in the healthcare industry doing project management and marketing. They will be assisting USEP with the American Recovery and Reinvestment Act programs.

**RETIREMENTS:** **Roger Bon** recently retired from the UGS after 21 years of service. His work focused on the coal resources of Utah, but he also investigated oil and gas, industrial minerals, and uranium/vanadium deposits, produced small and large mine permit maps, and published annual Utah mineral activity summaries. Roger was instrumental in launching the Industry Outreach Program where he was responsible for providing information, updates, and results of UGS energy and mineral projects to the industry through UGS co-sponsored conferences, exhibit booths, newsletters, Web site, and his many established contacts. He also served as President of the Utah Geological Association (UGA) and senior editor of UGA Publication 32, "Mining Districts of Utah." Roger's knowledge, expertise, and amiable personality will be greatly missed. We wish him well in his retirement!

**Bill Case** retired in June after 29 years of service with the UGS. Bill's geologic career with the UGS began with the former Applied Geology Program, where he worked on earthquake and landslide hazards. In the mid-1980s, Bill took the lead to develop and coordinate the Program's growing computer needs. By 1990, Bill's computer skills were employed full-time to coordinate and manage all of UGS's computers, thus becoming the UGS computer guru (to whom we all ran numerous times every day until his final day in June). Bill also worked as a geologist in the Geologic Information and Outreach Program. Bill's patience and incredible dedication to his job, along with his great camaraderie and sense of humor, will be greatly missed.

**Mage Yonetani** retired in June after 31 years of managing the UGS Library. Mage started as the librarian when the UGS was located in Research Park, and mustered through two major office moves—to Foothill Drive in 1991 and to the current location in the Department of Natural Resources (DNR) building in 1996, where her position expanded and she became the DNR Librarian. Mage's knowledge and professionalism combined with her cooperative, friendly spirit will be greatly missed. We wish Mage and Bill well in their retirement years together!

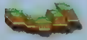
# teacher's corner

## Teaching Kits Available for Loan

The UGS first offered three rock and mineral kits (assembled by the son of a UGS employee as an Eagle Scout project) back in 1993 —essentially the beginning of UGS's education outreach program. Since then, the UGS has expanded its education outreach, including the number and variety of teaching kits offered. Currently, four different kits are available: Rock, Mineral, and Fossil; Landforms; Ice Age; and Dinosaur.

**Rock, Mineral, and Fossil kits** contain over 60 specimens (26 rocks, 27 minerals, and 16 fossils), a fossil environment map for Utah, and mineral testing tools. Teaching manual and activities geared to 4th and 8th grade science core curricula.

*Kits available: 10* *Loan period: one month* *Deposit: $50 refundable*



**Landforms kits** contain fault blocks, Wasatch fault fly-by video, maps, posters, a tectonics model, PowerPoint presentation, and a new teaching manual with numerous activities addressing the 5th grade science core curriculum.

*Kits available: 3* *Loan period: two weeks* *Deposit: $50 refundable*

**Ice Age kits** contain 14 fossil specimens, including a Saber-toothed cat tooth and jaw, a musk ox horn, and a giant sloth claw; a raised relief map of Utah showing locations of glaciers and Lake Bonneville; a PowerPoint presentation; and a teaching manual with suggested activities for most grade levels.

*Kits available: 3* *Loan period: two weeks* *Deposit: $50 refundable*

**Dinosaur kits** contain 36 cast specimens, including dinosaur bones, skulls, horns, skin impressions, teeth, claws, and a Stegosaurus plate; nine mini dinosaur replicas; teaching aids; a teaching manual; and activities for most grade levels.

*Kits available: 4* *Loan period: two weeks* *Deposit: $100 refundable*

**Stream tables** are also available for loan and include a tray approximately 4 feet long by 1 foot wide by 2 inches deep, sand, and easy-to-use gravity plumbing. Tables are self contained, providing a mess-free stream erosion and deposition model for classroom use.

*Tables available: 3* *Loan period: two weeks* *Deposit: (a) none required if loaned with a landform kit, or (b) $20 refundable without a kit.*

## Don't forget Earth Science Week!

Earth Science Week activities will be held this year October 4–7 (for activity details and further information, see **geology.utah.gov/teacher/esweek.htm**). Call 801-537-3300 to make reservations.

# GEOSIGHTS

## GLACIAL LANDFORMS IN BIG AND LITTLE COTTONWOOD CANYONS, SALT LAKE COUNTY, UTAH

*by Sandy Eldredge*

Big and Little Cottonwood Canyons contain some of the most dramatic glacial scenery in the Wasatch Range. This article highlights some of the numerous and varied glacial features in both canyons.

### Geologic Information

The Cottonwood Canyons and many of their tributaries and high-elevation basins were filled with hundreds of feet of glacial ice between 30,000 and 10,000 years ago. The Little Cottonwood Canyon glacier reached beyond the mouth of the canyon and extended into Lake Bonneville, calving ice bergs into the Ice Age lake. The Big Cottonwood Canyon glacier, however, advanced only about 5 miles down its canyon. Presumably this was due to less snow accumulation in Big Cottonwood's catchment area.

**Valley** (alpine) **glaciers** originate at the head of valleys in high mountain ranges and then flow down preexisting stream valleys. They erode and transport considerable amounts of rock debris, enabling them to significantly modify the landscape. Many distinctive erosional and depositional landforms result; however, this article addresses only the more prominent local features. Beautiful granitic rock that has been sculpted by glacial ice in both canyons enhances the spectacular rugged, mountainous scenery.

### Erosional Landforms and Features

Glaciers pluck and abrade a staggering amount of rock from the canyon walls and floors, which is then carried along with the moving ice. Thus, the hefty mass of rock material and ice perform some serious erosion. The valley bottom and walls are scoured vigorously, creating a deeper and much wider **U-shaped canyon**—one of the most distinctive valley glacial features.

At the head of canyons where glacial ice originates, glaciers carve out amphitheater-shaped basins (**cirques**) partially bounded by high, steep walls. Typically, small lakes (**tarns**) form in these depressions after the glaciers have retreated. Headward erosion cutting into the sides of a mountain peak by two or more glaciers chisels it into a sharp, often pyramid-shaped peak (**horn**). Between two adjacent glacial valleys or cirques, the dividing rock wall is eroded into a serrated, narrow ridge (**arête**).

Where tributary glaciers merge with the main glacier, the glaciers' surfaces are at the same level. However, the thicker main glacier erodes its canyon floor deeper than the tributaries so that when the glaciers recede, the floors of the tributaries are higher than the floor of the main valley —hanging above the deeper main canyon (**hanging valleys**).

*The Pfeifferhorn is an appropriately named peak; glaciers in Maybird Gulch (location of photo) and Hogum Fork to the west (photo right) carved the peak into a* ***horn****. The* ***cirque*** *at the head of Maybird Gulch is backed by a steep curved wall. The* ***arête*** *separating the tributary glaciers displays the characteristic narrow, jagged, and sharp ridge features often described as resembling the blade of a serrated knife. The glacial tributaries feed northward into Little Cottonwood Canyon.*

***Glacial striations*** *have been etched into smooth slabs of bedrock around Lake Blanche (****tarn****) in Mill B South Fork, a southern tributary of Big Cottonwood Canyon. Sundial Peak is in the background.*

Rock fragments embedded in the base of a glacier will carve multiple, parallel linear grooves into underlying bedrock (**glacial striations**) and clearly show the direction of glacier flow. Striations are abundant in both canyons, although most are not close to the roads. Several good places to see these features are around Cecret Lake at the head of Little Cottonwood Canyon in Albion Basin and around Lake Blanche in a tributary of Big Cottonwood Canyon.

### Depositional Landforms and Features

Glaciers deposit a chaotic mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape (**glacial till**). At the end of a glacier where melting dominates, the till is usually deposited in the form of a ridge (**end moraine**); a **terminal moraine** is the outermost end moraine marking the glacier's farthest point of advance. Similar ridge-like landforms are created along the sides of a glacier (**lateral moraines**).

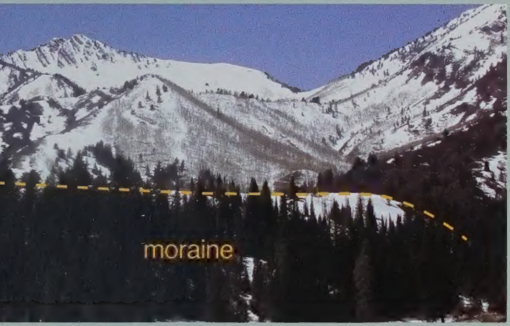
Rocks, including house-size boulders that are carried by glacial ice, may be deposited far from their source (**glacial erratics**). Erratics are often found scattered on top of different bedrock than what they originated from.

### Big Cottonwood Canyon

*(14.2 miles to Brighton, mileage begins at the junction with Wasatch Boulevard)*

The Big Cottonwood Canyon glacier reached only about 5 miles down the canyon where it abruptly ended. The lower 9 miles of the canyon are narrow and very twisty, which is a characteristic result of stream erosion.

At mile 9.0 (Reynolds Flat), the canyon suddenly widens and straightens, clear evidence that glaciers occupied the canyon from this point on up the canyon. The main glacier ranged in depth from 500 to 800 feet. **Glacial tributaries** (side canyons) add to the alpine scenery that now dominates. The first example is to the south where the U-shaped Mill D South Fork tributary leads up to a sharp, jagged ridgeline. This tributary glacier met the Big Cottonwood glacier at Reynolds Flat where they both stalled and did not advance below the tributary's terminal moraine here.



*Looking down canyon from Reynolds Flat at the* ***terminal moraine*** *deposited by the Mill D South Fork tributary glacier.*

Along the upper canyon are **moraines** (including a one-mile-long lateral moraine that is an aspen-covered 280-foot-high ridge, along the northeast side of the road below Brighton) and scattered white-colored granitic **glacial erratics**.

### Little Cottonwood Canyon

*(8.5 miles to Alta, mileage begins at the UT-210 and UT-209 junction)*

The Little Cottonwood Canyon glacier was the longest (12 miles) glacier in the Wasatch Range, extending beyond the canyon mouth and entering Lake Bonneville. The glacier ranged in depth from about 450 to 850 feet.

The first most obvious glacial feature is Little Cottonwood Canyon's world-class **U-shaped valley**. A photo and description of observable features at the canyon mouth are in "Utah's Glacial Geology" in this issue of *Survey Notes*. Also, see geology.utah.gov/surveynotes/geosights/gilbertpark.htm, which describes the G.K. Gilbert Geologic View Park just to the west of the canyon mouth.

**Hanging valleys**, often displaying scenic waterfalls, begin to appear within several miles on the south side of the canyon.

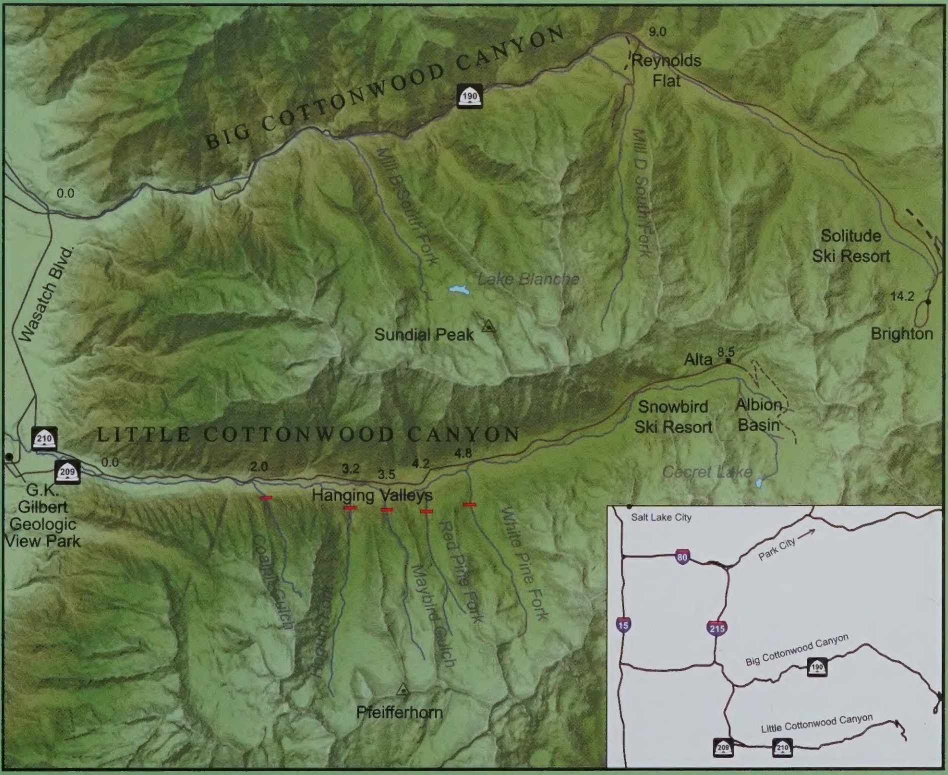
Other glacial features in the canyon include moraine remnants and glacial erratics. Also, cirques, arêtes, and horns can be seen up the glacial tributaries on the canyon's south side and near Albion Basin (accessible by vehicles in the summer) above Alta at the head of the canyon.

*Maybird Gulch shows the glacial tributary's U-shape and a waterfall cascading down from the hanging valley 3.5 miles up the canyon. Photo courtesy of Cali Mayer.*

*For additional information and more detailed maps about the Cottonwood Canyons, see geology.utah.gov/geo_guides/c_wasatch/index.php.*

**How to get there:** From Salt Lake City, take exit #304 from I-15 onto eastbound I-80, and after 5 miles bear right at exit #128 onto southbound I-215. Travel 5.9 miles, take exit #6 at 6200 South and turn left (east). Within 1 mile the road becomes Wasatch Boulevard near a gravel pit. Travel 1 more mile to a stoplight. Go left to enter Big Cottonwood Canyon, or continue straight (south) to go to Little Cottonwood Canyon.

From the mouth of Big Cottonwood Canyon, head south on Wasatch Boulevard 2.1 miles to a stoplight. Continue straight for over 1 mile on UT-210 to the mouth of Little Cottonwood Canyon.



# ENERGY NEWS

Newly developed Daneros mine entries. The mine is in the White Canyon district about 60 miles west of Blanding, Utah. The White Canyon district ores are in the basal Shinarump Conglomerate Member of the Upper Triassic Chinle Formation.

## URANIUM—

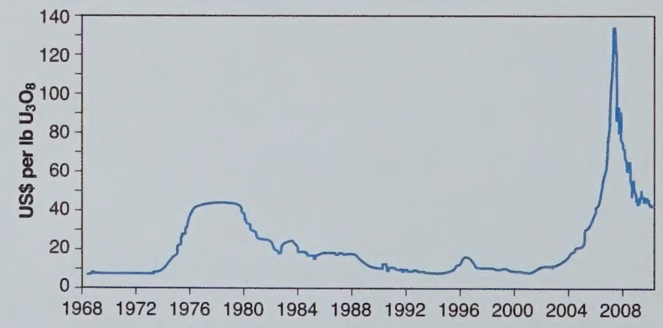
### FUEL FOR THE 21ST CENTURY?

*by Roger Bon*

World demand for uranium is increasing rapidly as the demand for electricity increases and more countries consider alternatives to carbon-based fuels. Over the past three decades, the U.S. has seen very little construction of new nuclear power plants, due in large part to public reaction following the incident at Three Mile Island in 1979. However, that may be changing as new energy legislation is being debated in Congress and incentives have recently been given to construct several nuclear facilities.

Prior to a surge in uranium prices beginning in 2004, all of Utah's 15 uranium mines were inactive or nearing permanent closure; most had been inactive since the early 1990s. The yearly average spot or short-term uranium price, which was about $8/lb in 2001, rose to $88/lb in 2007. The weekly spot price peaked at $137/lb in late 2007 before entering a precipitous decline that appears to have stabilized with the current price near $40/lb. These dramatic price fluctuations have affected uranium production and mine developments in Utah. As prices surged in 2004 and 2005, numerous mines and properties changed hands, and several inactive mines were being rehabilitated in preparation for production. The two leading companies in this endeavor were Denison Mines Corporation of Canada and White Canyon Uranium Ltd., of Australia.

International Uranium Corporation (IUC), a Canadian-based company with a long history of mining and milling on the Colorado Plateau, owned five uranium mines and the White Mesa mill in Utah. IUC merged its operations with Denison Mines in 2005 to form Denison Mines Corporation. In September 2006, Denison's Pandora mine was the first to go into production, and it is still operating. Denison next began rehabilitating its Rim mine late in 2007, and it was brought into production in early 2008. The Rim operated until early 2009, when it was idled. Denison's third mine to go into production, the Beaver, was rehabilitated in late 2008, went into production in early 2009, and is still active. Denison's fourth mine, the Tony M, hosts the largest remaining uranium reserve in Utah. When Denison acquired the Tony M mine in 2005, the mine had nearly 17 miles of developed workings, most of which were flooded. Mine development began in early 2007, and in addition to rehabilitating the mine, most of the surface facilities were rebuilt. The Tony M produced from September 2007 to November 2008, when it was idled. Denison's fifth mine, the Redd Block, remains inactive. Denison's mines in Colorado have undergone a similar history: rehabilitation, limited or no production, and then idled. As of July 2010, Denison's only operating mines on the Colorado Plateau were the Pandora and Beaver. However, Denison also has one operating uranium mine in northern Arizona that opened in late 2009, and produces a higher grade ore than the mines in Utah.



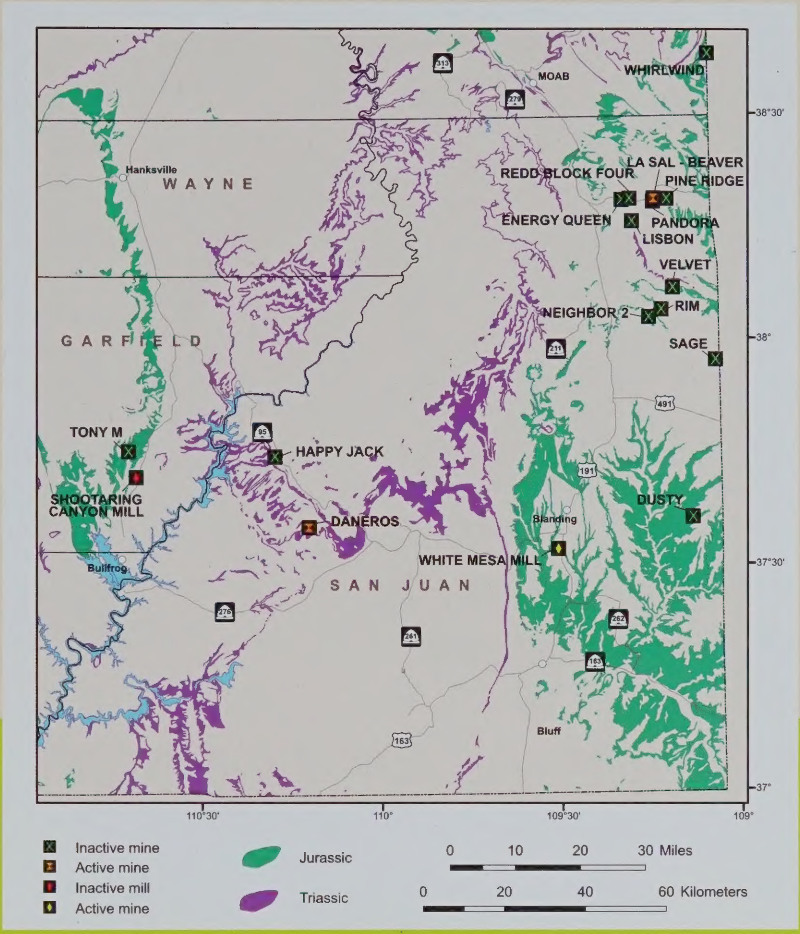
*Uranium spot prices from 1968 through mid-2010. Data courtesy of Trade Tech, (www.uranium.info).*

White Canyon Uranium has done a remarkable job of development in a short period of time. White Canyon's Daneros mine was permitted in May 2009, development began in July, and mining began in December. The Daneros is a relatively small, moderate-grade mine located near several historic uranium mines. The mine is ramping up production to about 50,000 tons per year. The ore is trucked to the White Mesa mill near Blanding, Utah, for processing under a toll milling agreement with Denison. The company is actively drilling properties near the Daneros for potential mine expansion.

All of the ore produced from the Colorado Plateau and northern Arizona is trucked to Denison's White Mesa mill for processing. Although relatively easy to mine, the Colorado Plateau uranium ore is of a lower grade than uranium ore mined elsewhere—typically 0.15 to 0.35 percent $U_3O_8$ and about 1 percent $V_2O_5$ (vanadium pentoxide). The mill, which began operating in the early 1980s, recovers both uranium and vanadium from ore, as well as from an alternate feed waste material that also contains relatively high-grade uranium. The 1800-ton-per-day mill can produce about 3 million lb of $U_3O_8$ , often referred to as yellowcake due to its color, and 4.5 million lb of $V_2O_5$, or black flake, annually. White Mesa began processing alternate feed material in 2005, and stockpiled ore from its own mines and other mines on the Colorado Plateau in 2008. The mill produced 614,000 lb of $U_3O_8$ and 501,000 lb of $V_2O_5$ from conventional ore and alternate feed material in 2009, and although spot uranium prices remain low, the mill will continue to operate because of long-term contract commitments at higher prices, relatively high vanadium prices, and low-cost alternate feed material. Uranium ore production in Utah went from 1200 tons from one mine in 2006 to 138,000 tons from four mines in 2008, and then to 103,000 tons from four mines in 2009.

While there is a lull in mining activity in the U.S., world demand for uranium continues to grow as new nuclear power plants are being built overseas, most notably in China, India, and Russia. In 2009, 436 nuclear reactors operated in 30 countries that produced about 15 percent of the world's supply of electricity. In addition, 56 nuclear reactors are under construction in 13 countries. Denison estimates that 570 nuclear reactors will be operating worldwide by 2020, which would represent an increase in nuclear generating capacity of more than 30 percent in just 10 years. Based on this scenario, Ux Consulting Company LLC (UxC), one of the nuclear industry's leading consulting companies, recently estimated that uranium demand will grow from 185 million lb of $U_3O_8$ in 2009 to 247 million lb in 2020. The World Nuclear Association reports that about 76 percent of current world demand is met from mined uranium, while the remainder is provided by reprocessed nuclear fuel, blending down of highly enriched uranium, and stockpiled reserves.

Could uranium become the "new" green fuel of the future? Is the current lull in mining in the U.S. the calm before the next boom? Will international suppliers step in to fill the demand? The answer to these questions will be answered in the next 10 to 20 years as the unrelenting demand for more carbon-free energy continues. Only time will tell how Utah's uranium industry will respond to these events.



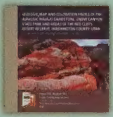
*Location and status of uranium mines and mills in Utah. Most uranium produced in Utah is from Mesozoic Jurassic (green) and Triassic (purple) sandstone and conglomerate.*

## FOR MORE INFORMATION:

Additional information on uranium and nuclear power can be found on the following Web sites: Energy Information Administration (eia.doe.gov), International Atomic Energy Agency (iaea.org), U.S. Nuclear Regulatory Commission (nrc.gov), UxC (uxc.com), and World Nuclear Association (world-nuclear.org). For additional information on Utah's mining industry, go to geology.utah.gov/utahgeo/rockmineral/index.htm#minactivity.

# NEW PUBLICATIONS

**Geologic map of the Clear Creek Mountain quadrangle, Kane County, Utah,** by Michael D. Hylland, CD (2 pl.), scale 1:24,000, ISBN 978-1-55791-834-5, **M-245** .................... **$14.95**



**Geologic map and coloration facies of the Jurassic Navajo Sandstone, Snow Canyon State Park and areas of the Red Cliffs Desert Reserve, Washington County, Utah,** by Gregory B. Nielsen and Marjorie A. Chan, CD (15 p., 2 pl.), **OFR-561** .................. **$14.95**

**Interim geologic map of the Shearing Corral quadrangle, Morgan, Rich, and Summit Counties, Utah,** by Jon K. King, 12 p., 1 pl., scale 1:24,000, **OFR-565** ....................................... **$13.95**

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**New techniques for new hydrocarbon discoveries—surface geochemical surveys in the Lisbon and Lightning Draw southeast field areas, San Juan County, Utah,** by David M. Seneshen, Thomas C. Chidsey, Jr., Craig D. Morgan, and Michael D. Vanden Berg, CD (61 p.), ISBN 978-1-55791-826-0, **MP-10-2** .......................... **$14.95**

**Sunnyside tar sand deposit: Data and references from industrial exploration projects,** compiled by J. Wallace Gwynn, DVD (5 p. + 24 data folders), **OFR-566** .................................... **$14.95**

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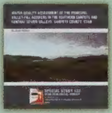
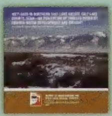


**Water-quality assessment of the principal valley-fill aquifers in southern Sanpete and central Sevier Valleys, Sanpete County, Utah,** by Janae Wallace, CD (132 p., 6 pl.), ISBN 978-1-55791-828-4, **SS-132** ......... **$19.95**



**Wetlands in northern Salt Lake Valley, Salt Lake County, Utah—an evaluation of threats posed by ground-water development and drought,** by Sandow M. Yidana, Mike Lowe, and Richard L. Emerson, 40 p., 6 pl., **RI-268** .......................................... **$14.95**

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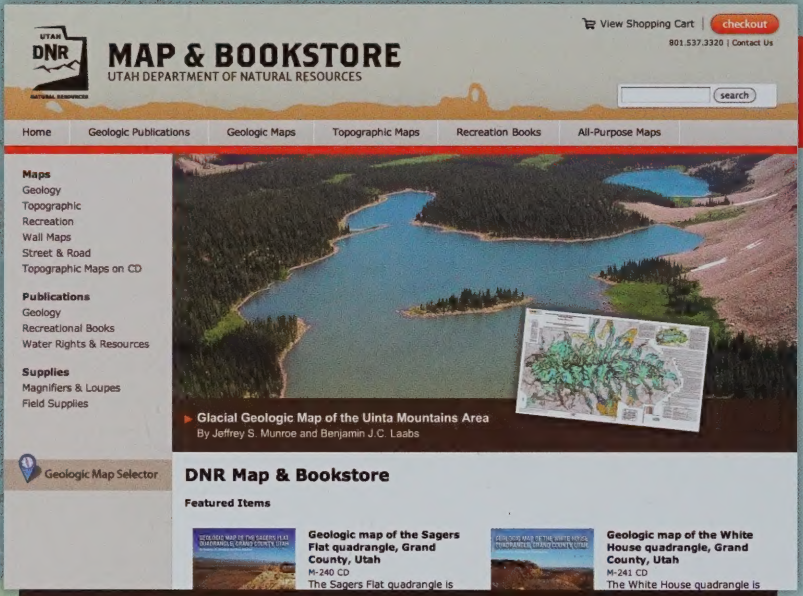

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